Technical Report

Demonstration of Advanced Geophysics and Classification Methods on Munitions Response Sites - East Fork Valley Range Complex Former Camp Hale

ESTCP Project MR-201230

April 2016

Ms. Victoria Kantsios
Mr. Brian Helmlinger
Ms. Cheryl Gannon
URS Group/AECOM

ESTCP

FINAL REPORT

Demonstration of Advanced Geophysics and Classification Methods on Munitions Response Sites

East Fork Valley Range Complex Former Camp Hale, CO

ESTCP Project Number: MR-201230

URS Project Number: 39455683

April 2016

URS Group, Inc.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
12-06-2013	Final Report	May - November 2014

4. TITLE AND SUBTITLE

Demonstration of Advanced Geophysics and Classification Methods on Munitions Response Sites

East Fork Valley Range Complex Former Camp Hale, CO

5a. CONTRACT NUMBER

W912HQ-12-C-0010

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

V. Kantsios, C. Gannon, B. Helmlinger

5d. PROJECT NUMBER

MR-201230

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

URS Group, Incorporated
2450 Crystal Drive, Suite 500
Arlington, VA 22202

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Environmental Security Technology Certification Program (ESTCP) Office
4800 Mark Center Drive, Suite 17D08
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)

ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This document serves as the Environmental Security Technology Certification Program (ESTCP) Demonstration Report for the demonstration of advanced geophysics and classification technologies on the Former Camp Hale, East Fork Valley Range Complex Munitions Response Site. This project is one in a series of projects funded by ESTCP to use advanced geophysical sensors and test data analysis tools for anomaly classification.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UL	58	V. Kantsios
Unclassified	Unclassified	Unclassified			**19b. TELEPHONE NUMBER** *(Include area code)* (703) 418-3030

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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ACRONYMS

CD	Cultural Debris
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DERP	Defense Environmental Restoration Program
DGM	Digital Geophysical Mapping
DoD	Department of Defense
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
ft	Feet
FUDS	Formerly Used Defense Site
GPS	Global Positioning System
ID	Identification
IMU	Inertial Measurement Unit
ISO	Industry Standard Object
IVS	Instrument Verification Strip
LM	Library Matching
MEC	Munitions and Explosives of Concern
MMRP	Military Munitions Response Program
MRA	Munitions Response Area
msl	Mean Sea Level
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
Nfa	Number of False Alarms
NRL	U.S. Naval Research Laboratory
Pclass	Probability of Correct Classification of TOI
QC	Quality Control
RI	Remedial Investigation
RRD	Range-related Debris
RTK	Real-Time Kinematic
SARA	Superfund Amendments and Reauthorization Act
SI	Site Inspection
TCRA	Time Critical Removal Action
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOI	Target of Interest
TSC	Trimble Survey Controller
URS	URS Group, Inc.
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This document serves as the Environmental Security Technology Certification Program (ESTCP) Demonstration Report for the Demonstration of Advanced Geophysics and Classification Methods on the East Fork Valley Range Complex Munitions Response Area (MRA) at Former Camp Hale, Colorado. This project is one in a series of projects funded by ESTCP to test the effectiveness of advanced geophysical sensors and physics-based data analysis tools for anomaly classification.

The project purpose is to locate and interrogate anomalies with the Time-domain Electromagnetic Multi-sensor Towed Array Detection System (TEMTADS) in a production environment to characterize portions of a 33.2-acre study area in East Fork Valley Range Complex MRA.

1.1 BACKGROUND

ESTCP contracted URS Group, Inc. (URS) to perform work in the demonstration area as close as possible to an actual production job, including obtaining stakeholder agreement for the project approach. URS used TEMTADS to perform a dynamic survey over approximately 10.5 acres of the study area and a cued survey of selected anomalies (1,742 anomalies) within approximately 7.6 acres of the study area. Survey data were processed by URS and Acorn Science and Innovation, Inc. (Acorn SI) using Oasis Montaj and classified by Black Tusk Geophysics (Black Tusk) using proprietary software. URS intrusively investigated 1,371 target locations and recovered 2,650 items. Project points of contact are in Appendix A.

1.2 OBJECTIVE OF THE DEMONSTRATION

Digital geophysical mapping (DGM) of former military ranges results in the identification and location of subsurface anomalies at a site. Typically, very small fractions of these anomalies are munitions and explosives of concern (MEC). The majority of these anomalies are harmless metallic objects (e.g., munitions fragments, small arms projectiles, range-related debris [RRD], or cultural debris [CD]). ESTCP and other collaborators have developed advanced EMI sensors and geophysical data processing methods that have proven effective at classifying subsurface metallic objects as either targets of interest (TOI) (i.e., objects having the size, shape, and wall thickness associated with MEC) or non-targets of interest (non-TOI) (i.e., harmless scrap metal). This demonstration serves to:

- Demonstrate the cost and performance of these sensors and methods on increasingly challenging MRSs,
- Train Military Munitions Response Program (MMRP) contractors on the application of these sensors and methods to facilitate technology transfer and industry-wide adoption, and
- Identify opportunities for potential improvement of the sensors and classification methods.

1.3 REGULATORY DRIVER

The ESTCP Live Site Demonstrations are executed under the guidance of the Department of Defense (DoD) MMRP, which is a portion of the Defense Environmental Restoration Program (DERP). DERP is the DoD program to execute environmental response consistent with the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986

(SARA); the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] 300); and Executive Order 12580, Superfund Implementation.

2.0   TECHNOLOGY

2.1   TECHNOLOGY DESCRIPTION

2.1.1   Geophysical Data Collection

URS used the TEMTADS 2x2 configuration developed by U.S. Naval Research Laboratory (NRL) in cart configuration generally as described in the "User's Guide TEMTADS MP 2x2 Cart, v2.00," dated 27 May 2014. The TEMTADS was paired with a Trimble R8 Real Time Kinematic (RTK) Global Positioning System (GPS) above the array on a mount that was taller (0.946 m instead of 0.8 m) than that described in the TEMTADS user's guide. The NRL-provided cart wheels were slightly larger (0.2125 m instead of 0.2 m) than those described in the user's guide (Figure 1).

Figure 1. TEMTADS 2x2 Cart Standard Configuration

For a portion of the field data collection, an alternate instrument configuration was tested where the standard transmitter (Tx) and receiver (Rx) cables were replaced with longer versions (Figure 2). Refer to Section 9 for additional information.

Figure 2. TEMTADS with Longer Tx/Rx Cables

2.1.2 Classification Methods

URS collected and processed dynamic and cued TEMTADS data using Geosoft Oasis Montaj UX-Analyze extension. Acorn SI and Black Tusk used software they developed to classify some anomalies as TOI using only the dynamic dataset. Acorn SI used a test version of UX-Analyze and Black Tusk used proprietary software.

Based on the data quality and target information that could be extracted from the dynamic survey, three potential approaches were taken:

- **Dynamic Classification:** Classify anomalies based on dynamic data alone (i.e., no cued data required);
- **Cued Classification:** Collect further non-intrusive (i.e., cued) data; or
- **Mag and Dig:** Proceed to excavation (i.e., no classification) in difficult areas with a high concentration of anomalies or accessibility issues.

Acorn SI and Black Tusk inverted dynamic data and selected anomalies where additional data collection (i.e., cued interrogation) were required. Black Tusk used Library Matching (LM), cluster analysis, and visual inspection to classify anomalies as TOI and non-TOI from the TEMTADS dynamic and cued data. Anomalies were classified into three categories:

- Category 0: Cannot analyze
- Category 1: Likely TOI
- Category 3: Likely non-TOI

An overview of data processing is provided in Section 6. Details of the classification methodology are described in Black Tusk's Camp Hale ESTCP report.

2.2   ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.2.1   TEMTADS Data Processing

While URS was able to process TEMTADS dynamic data, classification of dynamic TEMTADS data was not an option within the commercially available UX-Analyze extension of Geosoft Oasis Montaj. Additionally, only cursory data reviews were possible of the daily dynamic Instrument Verification Strip (IVS) measurements. UX-Analyze did not have the capabilities available to meet certain criteria of the standard operating procedures (SOPs) and performance objectives in the Demonstration Plan, specifically Sections 3.1 (cued) and 3.4 (dynamic).

3.0   PERFORMANCE OBJECTIVES

Performance objectives for the demonstration, provided in Table 1, serve as a basis for the evaluation of the performance and costs of the demonstrated technology. These objectives are for TEMTADS dynamic data and cued data collection, and data analysis and classification.

Table 1. Quantitative Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Data Collection Objectives			
Site-Specific Background	Establish background response	Background location response measurements	Comparison of background measurements at the same location during the course of the survey.
Along-line measurement spacing	Point-to-point spacing from dataset	Mapped survey data	100% <40cm along line spacing, 98% <25 cm along-line spacing, and 80% <15 cm along line spacing
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	100% of accessible area at 1.0-m line spacing, ≥85% coverage at 0.6-m line spacing and ≥98% coverage at 0.75-m line spacing calculated using UX-Process Footprint Coverage QC Tool
Repeatability of IVS measurements	Amplitude of IVS seed items Measured target locations	Twice-daily IVS survey data	*Advanced Sensor Dynamic Survey:* RMS amplitudes ±30% at the 14th time gate. Down-track inverted location ±30 cm *Advanced Sensors Cued:* Polarizabilities ±10%
Cued interrogation of anomalies	Instrument position	Cued mode data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location
Detection of all TOI	Percentage of detected seed items	Location of seed items and anomaly list	100% of seed items detected with 60 cm halo
Analysis and Classification Objectives			
Maximize correct classification of TOI	Percentage of TOI placed in Category 1	Prioritized anomaly lists and dig results	Zero TOI among excavated anomalies classified as non-TOI.
Maximize correct classification of non-TOI	Percentage of correctly classified non-TOI	Prioritized anomaly lists and dig results	>75% non-TOI excavated were classified in Category 3 while retaining all TOI
Specification of no-dig threshold	100% of TOI placed in Categories 1 or 2 and remainder of non-TOI placed in Category 3	Prioritized anomaly lists and dig results	Threshold specified to achieve criteria as stated above
Minimize number of anomalies that cannot be analyzed	Percentage of anomalies classified as Category 0	Inverted TEMTADS cued mode data and prioritized anomaly dig list	Reliable target parameters can be estimated for >95% of anomalies on the detection list

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Performance Objective	Metric	Data Required	Success Criteria
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Estimated and actual parameters (polarizabilities, XY locations, and depths [Z]) for seed items	Polarizabilities ±20% X, Y <15 cm (or 1 σ) Z <10 cm (or 1 σ)
Validation Digging			
Excavation of identified TOI	Percentage of anomalies classified as TOI verified to be "TOI" or "TOI-like" items	Prioritized anomaly list and dig results	>75% of intrusively investigated TOI anomalies are "TOI" or "TOI-like" anomalies
Excavation of identified non-TOI	Percentage of anomalies classified as non-TOI verified to be "non-TOI"	Prioritized anomaly list and dig results	100% of intrusively investigated non-TOI anomalies are non-TOI

3.1 OBJECTIVE: SITE SPECIFIC BACKGROUND

Establish a process to establish background response measurements.

3.1.1 Metric

The metric for this objective is to establish a background response for different areas of the study area.

3.1.2 Data Requirements

To select the background locations the dynamic data are analyzed for various locations throughout the site with low response that allow for easy and efficient data collection during the cued survey. Prior to the cued survey, the background locations are tested by taking a measurement at the flag and in each of the four cardinal directions at a distance equal to one-half of the width of the sensor array (0.4 m) away from the flag and measured for consistency.

The metric intended to use a forward model where the detection threshold TOI (60 mm mortar, horizontal, 0.6 m deep) was artificially added to the center background location. The background would be verified by separately subtracting each of the four offset backgrounds and performing a library match to the TOI. The background location would be considered valid if the library match from all four offset locations exceeded 0.9. However, this functionality was not available in UX-Analyze, so this was not evaluated.

3.1.3 Success Criteria

The individual background measurements are verified by quantitatively comparing to the initial background measurement to others taken at the same location during the course of the survey.

3.2 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The value of the collected dynamic data depends on the extent of coverage of the site that it represents. Gaps in coverage impede or prevent analysis of the data. Along-line measurement spacing must be close enough to ensure detection.

3.2.1 Metric

The metric for this objective is the percentage of data points within acceptable along-line spacing for areas where data were collected. Provisions for topography/vegetation interference have been made.

3.2.2 Data Requirements

Each mapped data file will be compared to this objective.

3.2.3 Success Criteria

This objective is considered met if 100% of the mapped data points are within 40 cm, at least 98% of the mapped data points are within 25 cm, and 80% of the mapped data points are within 15 cm of the accessible neighboring data points along the survey line.

3.3 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The ability of the TEMTADS dynamic survey to detect subsurface metallic objects depends on complete coverage of the site. Data spacing must be close enough to ensure detection. This objective concerns the ability to completely survey the site and obtain sufficient data coverage. Provisions for topography/vegetation interference have been made.

3.3.1 Metric

The metric for this objective is the footprint coverage as measured by the UX-Process Footprint Coverage QC Tool.

3.3.2 Data Requirements

Each mapped data file will be used to judge the success of this objective.

3.3.3 Success Criteria

This objective is considered met if the survey achieved at least 85% coverage at 0.6-m line spacing, 98% at 0.75-m line spacing, and 100% at 1.0-m line spacing calculated using the UX-Process Footprint Coverage QC Tool.

3.4 OBJECTIVE: IVS RESULTS

This objective demonstrates that the sensor system was in good working order and collecting valid data each day. The IVS will be surveyed twice daily. The amplitudes of the derived response coefficients for each emplaced item will be compared to the running average of the demonstration for reproducibility. At the beginning of the project, the IVS will be run five times to establish the baseline values. The extracted fit locations of each item will be compared to the reported ground truth and the running average of the demonstration.

3.4.1 Metric

The reproducibility of the measured responses of the sensor system to the emplaced items and of the extracted locations of the emplaced items defines this metric.

3.4.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients, location, and depth.

3.4.3 Success Criteria

The objective will be considered met if the RMS amplitude variation of the derived response coefficients is less than 30% and the down-track fit location of the anomaly is within 30 cm of the corresponding seeded item's stated location.

3.5   OBJECTIVE: CUED INTERROGATION OF ANOMALIES

To collect EMI data of the highest quality for UXO/clutter classification, the anomaly must be illuminated along its three principle axes. To ensure this, the sensor must be positioned directly over the center of the anomaly.

3.5.1 Metric

The metric for this objective is the center of the instrument is within the acceptable distance range from the actual target location.

3.5.2 Data Requirements

The GPS location from the QC seed emplacement and the cued instrument locations will be compared.

3.5.3 Success Criteria

The criterion is that the QC seed location is within 40cm of the array center.

3.6   OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

The collection of quality data should lead to a high probability of detecting TOI at the site.

3.6.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly selection threshold.

3.6.2 Data Requirements

The data will be used to judge this objective.

3.6.3 Success Criteria

The objective is considered met if 100% of the seeded items are detected within a halo of 60 cm.

3.7   OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

This is one of the two primary measures of the effectiveness of the classification method. This objective concerns the component of the classification problem that involves correct classification of TOI.

3.7.1 Metric

The metric for this objective is the number of items on the anomaly list for a particular sensor that can be correctly classified as TOI.

3.7.2 Data Requirements

A ranked anomaly list was prepared for the targets on the sensor anomaly list.

3.7.3 Success Criteria

The objective is considered to be met if zero TOI among excavated anomalies are classified as non-TOI on the ranked anomaly list.

3.8 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

This is the second of the two primary measures of the effectiveness of the classification method. This objective concerns the component of the classification problem that involves false alarm reduction.

3.8.1 Metric

The metric for this objective is the percentage of non-TOI items that are correctly classified as non-TOI by the classification method.

3.8.2 Data Requirements

A ranked anomaly list was prepared for the targets on the sensor anomaly list.

3.8.3 Success Criteria

The objective is considered to be met if more than 75% of the excavated non-TOI items were correctly labeled as non-TOI while retaining all TOI on the dig list.

3.9 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

Since all targets may not be dug, so the success of the project approach depends on the ability of an analyst to accurately specify their dig / no-dig threshold.

3.9.1 Metric

The probability of correct classification of TOI (Pclass) and number of false alarms (Nfa) at the demonstrator-specified threshold are the metrics for this objective.

3.9.2 Data Requirements

A ranked anomaly list was prepared with a dig / no-dig threshold indicated.

3.9.3 Success Criteria

The objective is considered to be met if the dig / no-dig threshold results in more than 75% of the excavated non-TOI items were correctly labeled as non-TOI, while correctly identifying all the TOI.

3.10   OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be considered TOI and reduce the effectiveness of the classification process.

3.10.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

3.10.2 Data Requirements

A list of all parameters was provided as part of the results submission, along with a list of those anomalies for which parameters could not be reliably estimated.

3.10.3 Success Criteria

The objective is considered to be met if reliable parameters can be estimated for more than 95% of the anomalies on the detection list.

3.11   OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

3.11.1 Metric

Accuracy of estimation of target parameters is the metric for this objective.

3.11.2 Data Requirements

Comparison of analyst's estimated parameters for the seed items to those expected.

3.11.3 Success Criteria

The objective is considered to be met if the estimated polarizabilities are within $\pm 20\%$, the estimated X, Y locations are within 15 cm (1 σ), and the estimated depths (Z) are within 10 cm (1 σ).

3.12   OBJECTIVE: EXCAVATION OF ANOMALIES

The collection of quality data should lead to excavating anomalies as either TOI or non-TOI.

3.12.1 Metric

The metric for this objective will be the percentage of items that were excavated and correctly classified as TOI or non-TOI.

3.12.2 Data Requirements

The anomaly list and dig results will be used to judge the success of this objective.

3.12.3 Success Criteria

The objective will be considered to be met if greater than 75% of the items identified as TOI are TOI or TOI-like anomalies and 100% of the items identified as non-TOI are non-TOI.

4.0   SITE DESCRIPTION

Former Camp Hale is located approximately 70 miles west of Denver, Colorado, in the Rocky Mountains. The ESTCP Live Site Demonstration was conducted within a portion of the 382-acre East Fork Valley Range Complex MRA of Former Camp Hale. The East Fork Valley Range Complex is located approximately 10 miles south of Red Cliff and 18 miles north of Leadville east of U.S. Highway 24. The East Fork Valley Range Complex is located in Lake County in the White River National Forest. Figure 3 is a location map of Former Camp Hale, and Figures 4 and 5 are maps of the ESTCP study area.
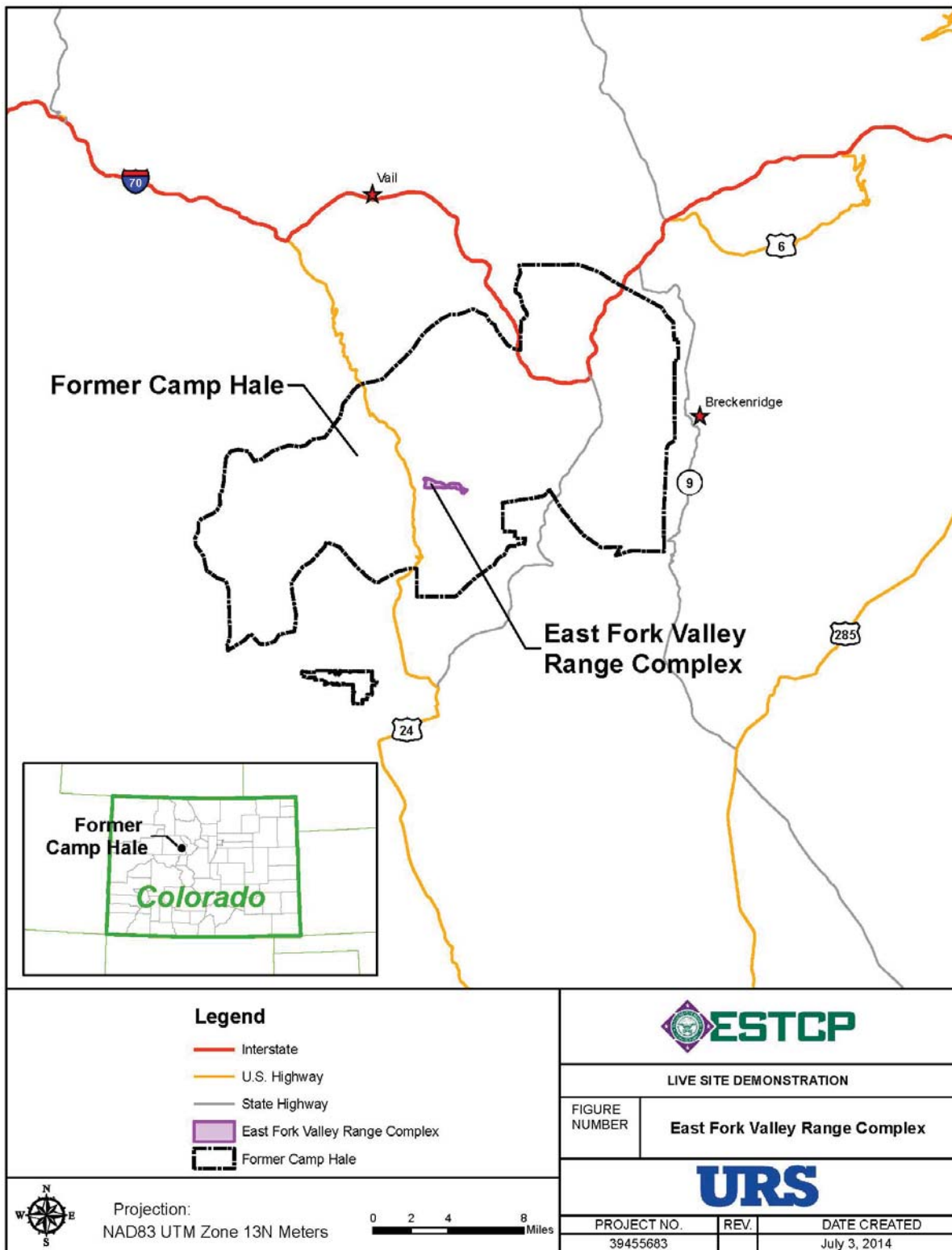
Figure 3. Map of Former Camp Hale

Aerial image from Microsoft dated August 2011
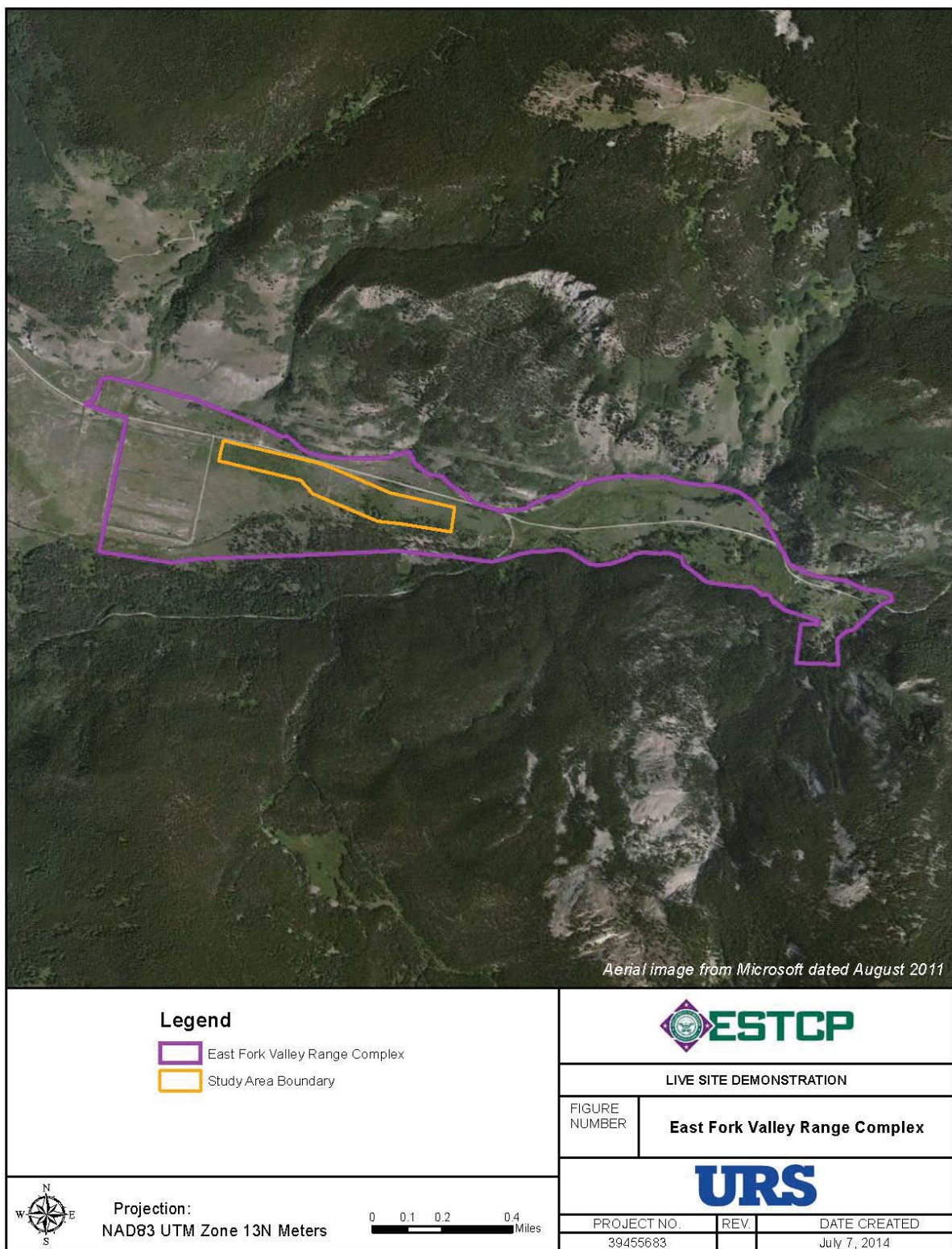
Figure 4. East Fork Valley Range Complex MRA and ESTCP Study Area
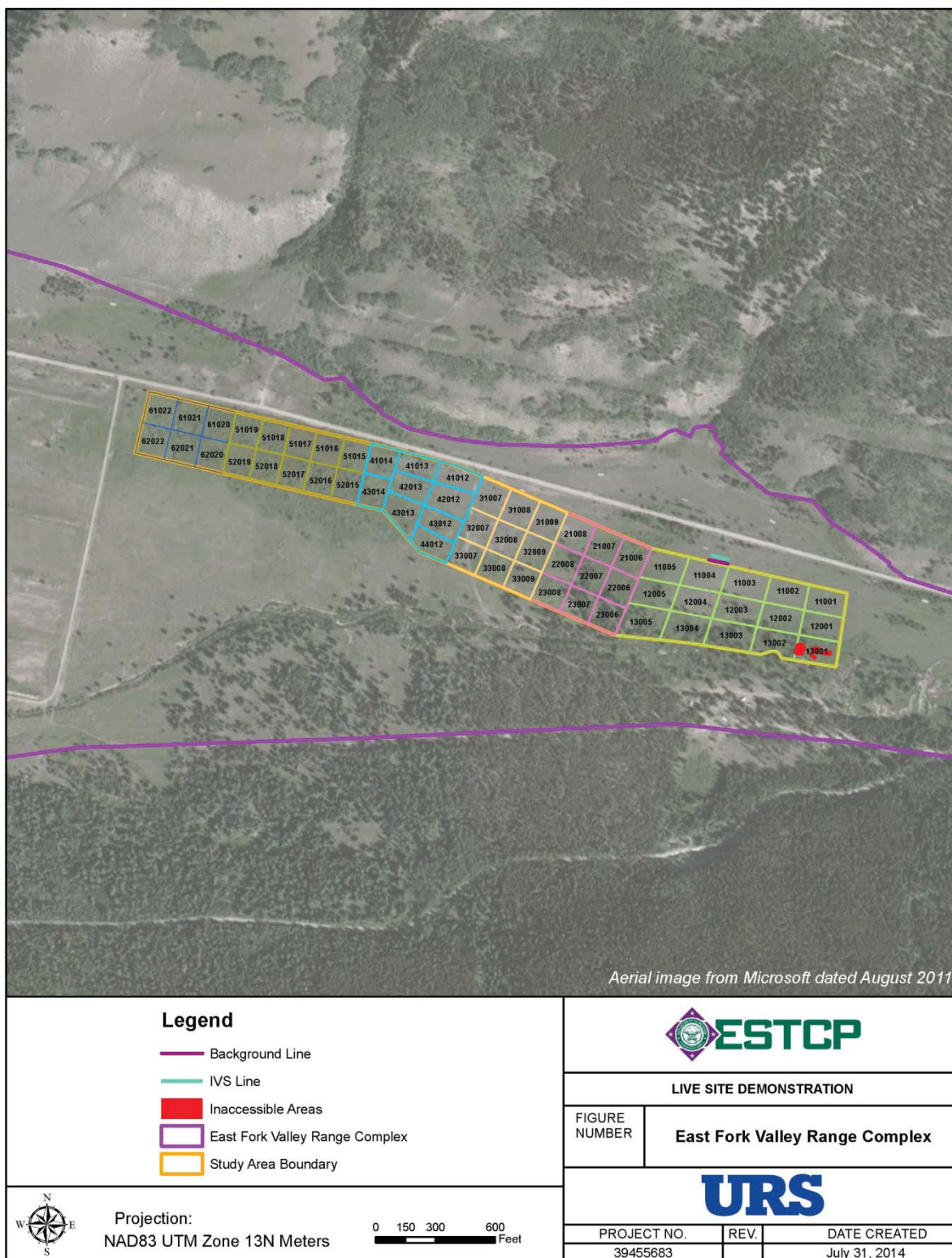
Figure 5. Former Camp Hale ESTCP Study Area

4.1 SITE SELECTION

This site was chosen as one in a series of sites for demonstration of the munitions classification process. Sites including this one provide opportunities to demonstrate the capabilities and limitations of the classification process on a variety of site conditions that are likely to be encountered on production sites.

Former Camp Hale was selected for demonstration because construction is proposed to reroute the East Fork of the Eagle River through the study area. The site is in the East Fork Valley, which is flanked by mountains on the north and south. Dense shrubs and grass were trimmed prior to geophysical data collection, but trees were not altered. Several portions of the site had high concentrations of evergreen trees.

4.2 SITE HISTORY

Camp Hale was established in 1942 and used by the Army until 1965 for winter and mountain warfare training. It was home to the Army 10th Mountain Division. Additionally, from 1959 to 1965, the Central Intelligence Agency used portions of Camp Hale for secret training. In 1966, Camp Hale was returned to the USFS. In 2001 and 2003, Time Critical Removal Actions (TCRAs) were performed that encompassed the whole of the East Fork Valley Range Complex (Shaw 2013).

The EFV Range Complex MRA is part of the White River National Forest, Holy Cross Ranger District, and former Camp Hale is a National Historic Site. The USFS operates two active campgrounds, the East Fork Group Campground (south of the ESTCP study area) and Camp Hale Memorial Campground (west of the ESTCP study area). The MRA is accessible to the public and used for recreation, including hiking and snowmobiling. The Colorado Trail runs through the MRA and other trails are present in the vicinity (Shaw 2013).

4.3 SITE GEOLOGY

Camp Hale is located in the Southern Rocky Mountains physiographic province. The southern Rocky Mountains consist primarily of a group of north-south mountain ranges of roughly anticlinal structure, with cores of igneous and metamorphic rocks flanked by steeply dipping sedimentary rocks. The valley floors range in elevation from about 9,310 to 9,660 ft above mean sea level (msl) and the topographic high points range from 9,400 to over 14,000 ft above msl (Shaw 2008a).

The former Camp Hale property is located in the Eagle River Valley in an area previously known as Eagle Park. Carved by glaciers and dammed by a glacial moraine, the mountain basin contains thick lake, stream, and glacial deposits. A Precambrian fault zone several hundred feet wide may have made these rocks easier to erode. On the cliffs in Eagle Park, Precambrian rocks are overlain by Cambrian quartzite and a whole sequence of Paleozoic sedimentary rocks. These rocks dip gently southeastward, continuing to the Mosquito Range (Shaw 2008a).

The Sawatch Range to the west of Camp Hale is composed of peaks made of Precambrian gneiss and schist. The boundary between these rocks and those of the Mosquito Range is somewhere underneath the Arkansas River Valley to the south, and the Eagle River Valley. In the south central portion of Camp Hale, the Tennessee Pass represents the dividing line between the drainage of the Arkansas River to the south and the Eagle River to the north. The Continental Divide runs along the Tennessee Pass, crossing here from the Front Range to the Sawatch Range.

Northeast of the Pass, forming a high ridge, a thick cliff-forming sill of intrusive igneous rock is sandwiched between Pennsylvanian rock layers. The general area is mineralized as evidenced by the presence of the Climax Mine (Shaw 2008a).

4.4   MUNITIONS FIRED ONSITE

According to the SI (Shaw 2008b), the specific types of conventional munitions used at Camp Hale were:

- Small arms: .22-, .30-, .45-, and .50-caliber ammunition;
- Demolition and bulk explosives;
- Hand Grenades: practice, smoke, and fragmentation;
- Rifle Grenades: practice, smoke, and high-explosive anti-tank (HEAT);
- Landmines: Mine, Anti-Tank, Practice, M1; Mine, Anti-Tank, HE, M1A1;Mine, Anti-Tank, M4;
- Rockets: 2.36-inch rockets (bazooka) – practice, smoke, and HEAT; 3.5-inch rocket (bazooka) – practice, smoke, and HEAT; 3.25-inch anti-aircraft target rockets; 2.75-inch aircraft rockets;
- Mortars: 60mm, 81mm, and 4.2-inch – practice, illumination, and HE; and
- Projectiles: 37mm, 40mm, 57mm, 75mm, 76mm, 90mm, 105mm, 106mm, and 155mm HE and HEAT

5.0 TEST DESIGN

At the Former Camp Hale demonstration site, URS performed:

- Overall site preparation and management (e.g., site preparation, validation digging), and
- TEMTADS dynamic and cued survey data collection and processing.

During site preparation activities, URS trimmed vegetation and planted blind seeds at the demonstration site. URS collected both dynamic and cued mode data using the TEMTADS 2x2 cart. URS processed the dynamic and cued TEMTADS data. Acorn SI and Black Tusk used dynamic classification software to identify targets that required cued interrogation. Black Tusk geophysicists classified both the dynamic and cued TEMTADS data. URS subsequently performed intrusive investigation using the Black Tusk ranked anomaly list.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

- **Demonstration/Work Plan Development**: URS prepared a demonstration plan describing site preparation, geophysical data collection, TEMTADS data processing, and intrusive investigation activities for this project.
- **Site Preparation:** URS cut dense shrub and grass vegetation to 15 cm above ground surface to prepare the site for advanced sensor data collection. Mature trees were unaltered.
- **TEMTADS Data Collection:** URS collected dynamic survey data over 10.5 acres using TEMTADS 2x2 in a cart configuration with a nominal line spacing of 0.4 m. URS also collected cued data over 1,742 anomalies identified during the dynamic survey.
- **TEMTADS Data Processing**: URS used the Geosoft UX-Analyze software package to process the dynamic and cued TEMTADS data.
- **TEMTADS Data Analysis and Classification**: Both Acorn SI (using a test version of UX-Analyze) and Black Tusk (using proprietary software) inverted dynamic data and selected targets requiring cued interrogation. Black Tusk classified both dynamic and cued data using LM, cluster analysis, and visual inspection to create a ranked anomaly list.
- **Intrusive Investigation**: URS intrusively investigated 2,650 anomalies from 1,371 target locations. Each anomaly was photographed and attribute information (e.g., nomenclature, size, and depth) was captured and provided to the ESTCP Program Office.

5.2 SITE PREPARATION

URS team members arrived on-site prior to arrival of the geophysical data collection team to set up project equipment and oversee the installation of two geodetic control points. Before geophysical data collection began, URS UXO technicians escorted the vegetation cutting team and emplaced blind seed items (58 medium Industry Standard Objects [ISO]) at the site.

5.3 CALIBRATION ACTIVITIES – INSTRUMENT VERIFICATION STRIP

URS used an IVS to verify the proper operation and function of the geophysical equipment and to measure site noise readings of the TEMTADS before and after each day of field data collection. The IVS also served to verify that geo-location systems provided accurate sensor location data. The IVS was installed consistent with the specifications and descriptions contained in *Geophysical System Verification (GSV): A Physics-Based Alternative to Geophysical Prove Outs for Munitions Response* (ESTCP 2009). ISOs were used as reference seed items. The IVS

contained one blank location and four seed items of the sizes, at the depths, and in the orientations listed in Table 2. A background IVS path was established parallel to and offset from the seeded IVS to collect dynamic background noise measurements.

Table 2. Former Camp Hale Instrument Verification Strip

Item ID	Description	Easting (m)	Northing (m)	Depth (m)	Inclination	Orientation
IVS Seed_1	Medium ISO	388914.091	4364398.283	0.20	Horizontal	Along Track
IVS Seed_2	Medium ISO	388918.860	4364397.052	0.18	Horizontal	Along Track
IVS Seed_3	Medium ISO	388923.748	4364395.793	0.23	Horizontal	Along Track
IVS Blank_4	Medium ISO	388928.460	4364394.643	N/A	N/A	N/A
IVS Seed_5	Medium ISO	388933.297	4364393.468	0.30	Horizontal	Along Track

* Coordinates UTM Zone 13N, NAD83.

5.4   DATA COLLECTION – TEMTADS ADVANCED SENSOR IN DYNAMIC SURVEY MODE

5.4.1   Sample Density

The dynamic survey consisted of complete coverage in the study area and subsequent data processing to identify metallic targets and create a prioritized target list. Figure 6 shows the dynamic data collection with standard (top) and longer (bottom) Tx/Rx cables. Data were collected along parallel transects with 0.4 m nominal separation between transects, and at a sample rate and survey pace slow enough to ensure nominal down-line spacing of less than 25 cm. Survey position were recorded and logged during the survey using an RTK GPS. Survey lanes were marked using water soluble spray paint and/or non-metallic pin flags. Areas within established grids that could not be mapped because of vegetation were noted in the geophysical logbook.

Figure 6 TEMTADS Dynamic Data Collection

5.4.2   Quality Checks

IVS: Survey personnel collected dynamic data over the IVS in each direction at the beginning and end of the data collection day. The afternoon IVS was not collected on 15 and 28 August due to the sudden onset and persistence of inclement weather. Mid-day IVS data also were collected during portions of the project due to unpredictable weather and at the request of the Black Tusk geophysicists.

Background IVS: This test consisted of alternating passes over the background IVS lane at the beginning of each day. Responses were monitored for consistency and overall noise levels during data analysis.

Battery Strength Test: At the beginning and throughout the day, the survey personnel checked the battery power and replaced batteries as necessary.

Verify Configuration: Prior to data acquisition, the field team reviewed the acquisition software configuration.

5.4.3   Data Summary

Raw data were collected and stored by the TEMTADS system as .tem files. The data collection software provided the operator with the ability to input a prefix for the root name of the file. For site data, the field team used the Julian day and project grid number as the root name, and for IVS, the operator input the Julian day and IVS version number (e.g., 01 for morning, 02 for afternoon) as the root name. For both file types, the data collection software appended a unique sequential numerical identifier to the end of each root file name. The raw data files were transferred to a separate computer and checked against the field notes for file name accuracy and renamed, if necessary. The .tem files were converted to .csv files for import into data processing software using Convert TEMTADS v3.0.0, a software program provided by NRL.

Discrete data files were created for each of the following events:

- IVS data collection;
- Transect data collection;
- System issues impacting data quality.

5.5   DATA COLLECTION – TEMTADS ADVANCED SENSOR IN CUED MODE

5.5.1   Sample Density

The cued survey consisted of collecting static data over 1,742 anomalies identified from the TEMTADS dynamic survey data. Measurements were repeated as necessary due to sensor offsets relative to the anomaly source or other data quality issues. Background responses were measured periodically where no metallic source was known to be present. The field team collected a total of 2,468 cued data measurements including re-collect, background, IVS, and sensor function tests.

The survey team used the Trimble TSC and RTK GPS to navigate to each previously identified anomaly location and positioned the array. The operator used the tablet to collect a cued data measurement (Figure 7). The instrument's pitch, roll, and yaw angles were automatically measured by the inertial measurement unit (IMU). These angles and the GPS measurements were used to calculate the center of the sensor location.

Figure 7. TEMTADS Cued Data Collection

The TEMTADS system allows for a real-time single-dipole inversion by the field team using the tablet. Using this function, the field team checked the instrument response and ensured the sensor

was centered over each anomaly. If the sensor was located greater than 30 cm away from the center of a detected anomaly, the field team adjusted the sensor location accordingly and collected another cued data measurement. The GPS coordinate and cued data for the new location was identified with the original anomaly identification (ID) plus a modifier indicating that it was an added data point offset from the original anomaly location.

5.5.2 Quality Checks

IVS: Cued responses were collected over each item in the IVS at the beginning and end of each day to demonstrate response repeatability over known sources. These responses were also used as training data for classifier routines. The afternoon IVS on 3 October was not collected due to a TEMTADS computer failure.

Sensor Function Test: At the beginning of the day or as necessary, data collection teams performed a sensor function test using the NRL-provided reference item and pre-programmed reference values.

Battery Strength Test: At the beginning and periodically throughout the day, data collection teams checked the battery power remaining and replaced batteries as necessary.

Background Response Measurement: Cued responses were collected at regular intervals at locations identified by the geophysicist where no metallic source was known to be present based on dynamic data results. These locations represent the typical geologic response of the cued area. To establish a background location, responses were measured in the center of the proposed background location as well as the four cardinal directions at 0.4 m offsets from the center. After data review by the geophysicist, the background location was marked for use by the field team. The nominal interval between background response measurements was one hour. Additional backgrounds were taken due to equipment restart, transmitter battery replacement, or changing field conditions (e.g., rain).

Test Pit: Test pit data were collected at the beginning of the project to establish instrument responses for the TOI (i.e., 60 mm mortar, horizontal, 0.6 m deep). Data were also collected on the background IVS by emplacing a medium ISO at 0.45 m and 0.6 m below the ground surface to measure responses.

Verify Configuration and Initialization Files: Prior to any data acquisition, the field team reviewed the configuration and initialization files for the acquisition software to confirm they had the appropriate TEMTADS setup.

5.5.3 Data Summary

Raw data were collected and stored by the TEMTADS system as a pair of files with the same root name and two different file extensions (.tem and .gps). For site data, the field team used the Julian day as the file name prefix and the anomaly number (i.e., grid number and anomaly identification) as the root name. If a re-collect was necessary, the operator added an alphabetic character suffix (e.g., "a" for first recollect, "b" for second). For the IVS, the operator input the Julian day and IVS version number (e.g., 01 for morning, 02 for afternoon) as the prefix and seed item identification number as the suffix. Background and sensor function test measurements used the Julian day and a unique sequential number as the prefix with an automatically generated suffix (i.e., "b" for background, "sf" for sensor function). The raw data files were transferred to a separate computer and checked against the field notes for file name accuracy and renamed, if

necessary. The .tem files were converted to .csv files for import into data processing software using Convert TEMTADS v3.0.0 software program provided by NRL.

Discrete data files were created for each of the following events:

- Each IVS target;
- Each background point;
- Each target anomaly location;
- Each target anomaly offset; and,
- Each system issue impacting data quality (e.g., program froze, GPS error, movement caused by loose soil or strong wind).

5.6 VALIDATION

5.6.1 Excavation Procedure

Intrusive investigations were completed in the Former Camp Hale demonstration site to determine whether the identified targets were MEC, munitions debris, or harmless scrap.

Black Tusk developed a target list from processing and classifying both the dynamic and cued advanced sensor data. Additionally, several areas were not classified and proceeded directly to excavation (mag and dig) due to either a high concentration of anomalies or data collection accessibility issues (i.e., terrain, trees). The target list, in UTM coordinates with expected depth below ground surface, was provided to the reacquisition teams in tabular and grid map form on a Trimble Yuma tablet for recording electronic field notes and on a Trimble TSC3 for GPS navigation and recording. The reacquisition team navigated to the target location with Trimble TSC3 and R8 RTK GPS. Daily functional QC tests were conducted for all reacquisition equipment, including Schonstedt ferrous metal detectors and RTK GPS.

Subsurface anomalies were manually excavated in accordance with EM 385-1-97 (USACE 2008). If no metallic objects greater than 2.5 cm were found after digging the reacquisition target location within a 30-cm radius circle to 10 cm below the specified depth, URS abandoned the dig location and reported the result as "no contact."

5.6.2 Data Recording Procedure

The following data were recorded during intrusive investigation of anomalies.

- **Item Location**: The location of the item was recorded with an RTK GPS to a horizontal precision of 3 cm.
- **Depth**: The depth was measured in centimeters using a ruled straight edge from a horizontal guide at ground surface to the approximate center of the metal item.
- **Identification**: The item was described if it could be identified (e.g., 4.2-in. mortar base plate, aluminum can, large bolt, nail).
- **Digital Photograph**: A digital photograph of all metal items found at each anomaly location was taken with the items in front of a background with visible ruled markings in centimeters and the anomaly number.
- **Number of Contacts**: URS recorded the number of discrete metal items (greater than 2.5 cm in size) found during the investigation of the anomaly location.

If more than one metal item was found when excavating a single target location, each item was recorded with an identical anomaly number.

5.6.3   Post Clearance

URS bagged all items recovered from each hole in a bag marked with the anomaly number. On completion of each anomaly, the hole was refilled to grade. Material potentially presenting an explosive hazard (MPPEH) was inspected and certified as material documented as safe (MDAS) by qualified UXO technicians. MDAS was shipped to a qualified scrap metal processor for final disposition.

5.6.4   Validation Results

Dig results included detailed descriptions, actual recovery locations, and photographs. All the seed items in the study area were recovered. Three MEC items were found; one 60-mm illumination round and two 81-mm mortars. All MEC were properly disposed. Figure 8 shows a digital photograph of each of the recovered MEC items and relevant data.
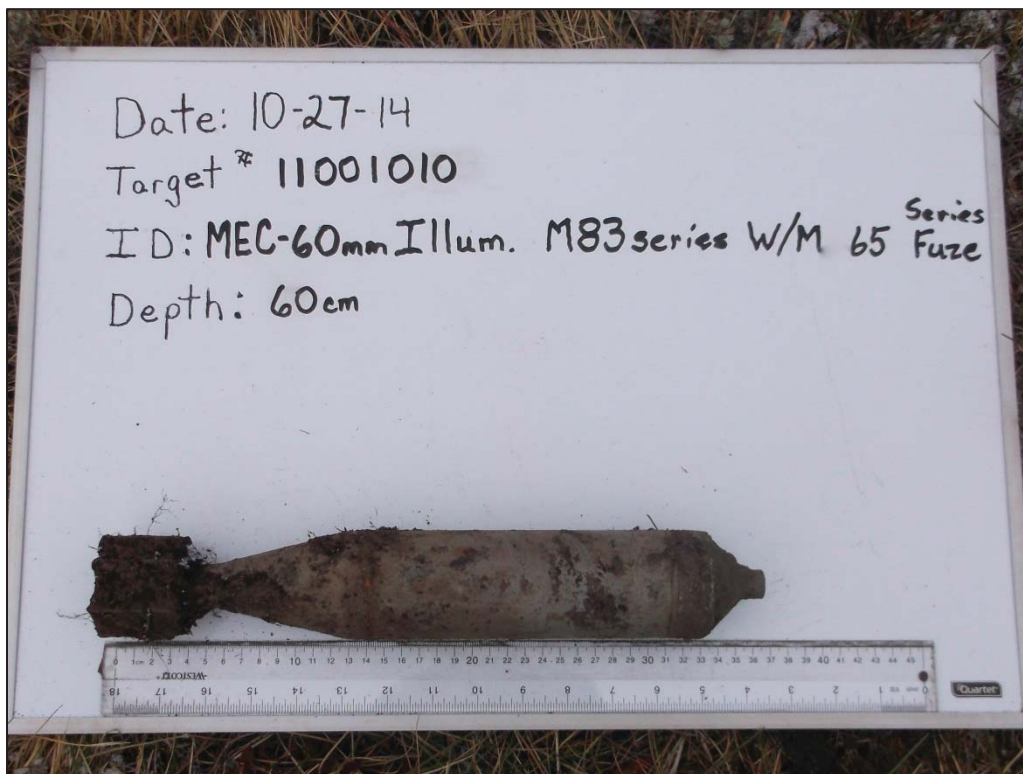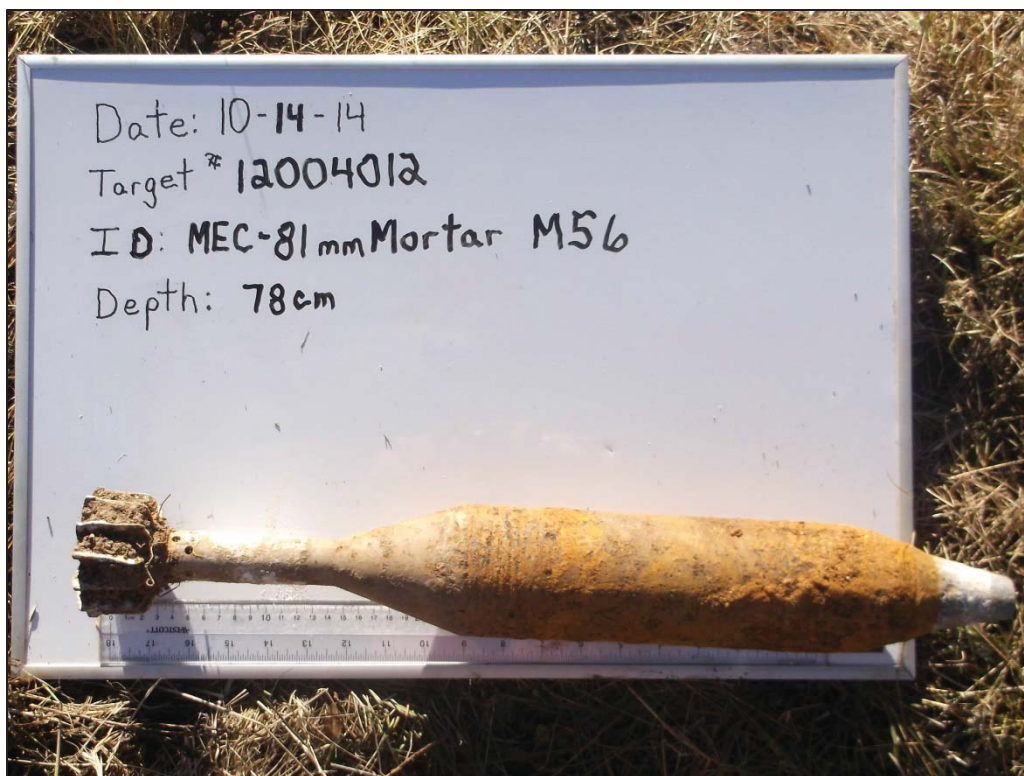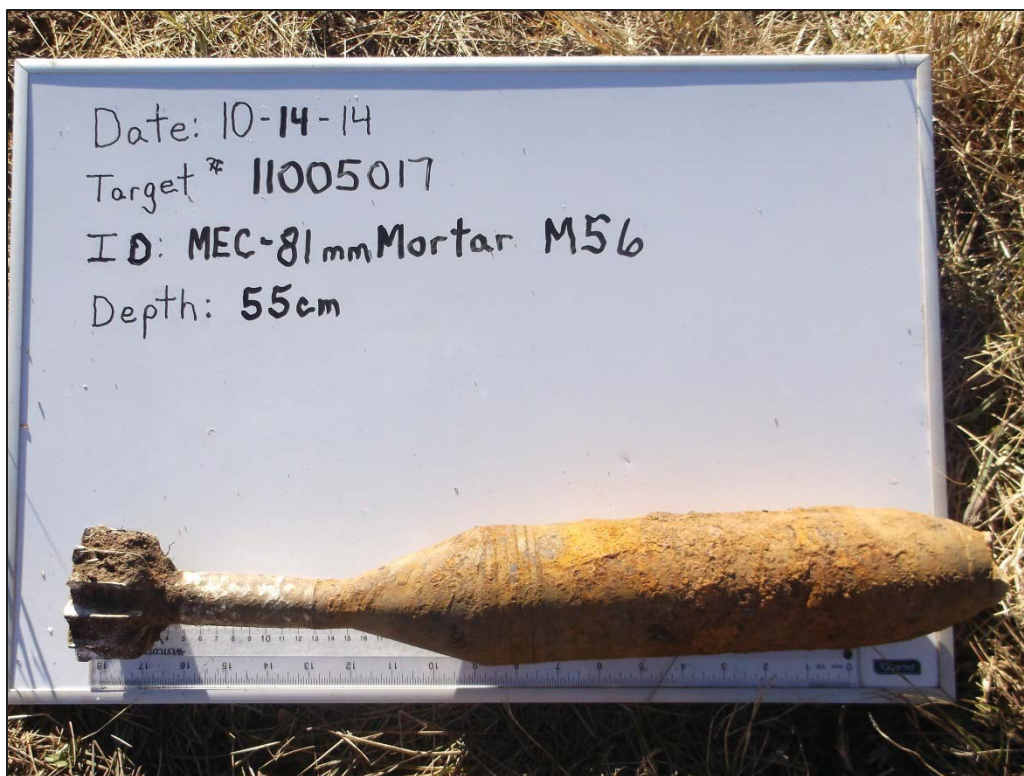
Figure 8. MEC Recovered at Former Camp Hale

5.6.5 Quality Assurance Digs

Through coordination with CDPHE and ESTCP, URS agreed to validate performance of the overall study, by selecting an additional 110 anomalies to verify the TOI/non-TOI threshold established for this project. This effort was to qualitatively evaluate how well the physical properties of the recovered TOI/non-TOI targets matched predictions.

The following criteria were used to develop the verification digs:

- UXO-like targets: 15
- Additional cued anomaly digs to get to 50 digs past final TOI: 8
- Additional dynamic data from grids 1100X 1200X to get to 50 digs past final TOI: 27
- Additional dynamic data from grids 1300X to get to 50 digs past final TOI: 25
- Randomly selected anomalies: 35

Anomalies excavated during the validation digs matched the established criteria for each class of anomalies. No TOI were found thereby providing the additional data quality assurance requested by CDPHE and ESTCP for the Camp Hale ESTCP project.

6.0 DATA ANALYSIS AND PRODUCTS

URS used the UX-Analyze extension contained in Geosoft Oasis Montaj version 8.2 to process TEMTADS field data. URS transmitted daily raw field data to Black Tusk and Acorn SI to classify dynamic data (where possible) and select targets that required cued data collection. URS used the Black Tusk-developed ranked anomaly list that incorporated dynamic data classification. Refer to the Black Tusk ESTCP report for information regarding the dynamic and cued classification processes.

6.1 TEMTADS DYNAMIC DATA

6.1.1 Dynamic Processing

URS imported and processed dynamic data files by day and grid. The processing procedures relied heavily upon the scripts and workflows developed by SAIC/Leidos. The first set of scripted commands filtered the transmitter currents, output reports on current channels, calculated time differences, flagged and interpolated over records with the same time, and calculated speed and heading. The second set of scripted commands created the "_located" database with median filtered monostatic responses, and created the channel of time gates 0 through 16 skipping time gate 1. Time gate 1 was not used due to inherent instrument noise.

6.1.2 Evaluation of Dynamic Data Quality and Identification of Anomalies

Black Tusk and Acorn SI picked peaks and inverted the dynamic data based on a detection threshold consistent with a 60 mm mortar (medium ISO) at depth of 60 cm, resulting in an initial list of dynamically-selected anomalies. Based on an evaluation of the quality of the data at each anomaly, the team decided to address each anomaly in one of three ways: Dynamic Classification, Cued Data Collection, or Mag and Dig.

6.1.2.1 Dynamic Classification

Where dynamic data were of sufficient quality to classify anomalies as either TOI/non-TOI, these anomalies were placed on the dig list. This was the preferred project approach by the project team (ESTCP, CDPHE, URS, Black Tusk, and Acorn SI). Black Tusk and Acorn SI performed classification of dynamic data using their proprietary software and a testing version of UX-Analyze, respectively.

6.1.2.2 Cued Anomaly Selection

Where dynamic data was not of sufficient quality to make a TOI/non-TOI decision, cued data were collected and classified for these anomalies. Both Acorn SI and Black Tusk participated in picking cued targets within the study area based on the dynamic TEMTADS data.

Black Tusk reviewed the dynamic data and applied several decision criteria to select anomalies for cued data collection:

- Anomalies with poor data coverage,
- Anomalies with significant elevation variation,
- Poor dipole fits, and
- Anomalies with a source depth greater than 0.3 m.

Generally, cued data were not collected where the following criteria were met. However, the project team collected cued data on a subset of ISOs and 0.50-caliber projectiles for confirmation.

- Dynamic classification indicated a seed item (medium ISOs),
- Dynamic classification indicated small arms (0.50-caliber projectiles), and
- Dynamic data indicated target size equal to or smaller than 0.50-caliber projectile.

6.1.2.3 Mag and Dig

After review of the dynamic data, the decision to use mag and dig was deemed the only option for portions of the study area. High densities of anomalies were identified in the central portion of the project area (Figure 9). Additionally, steep terrain and tree cover affected GPS coverage (i.e., other than Fix Quality 4, RTK) and proved difficult for data collection in the southeastern portion of the project area (Figure 10).
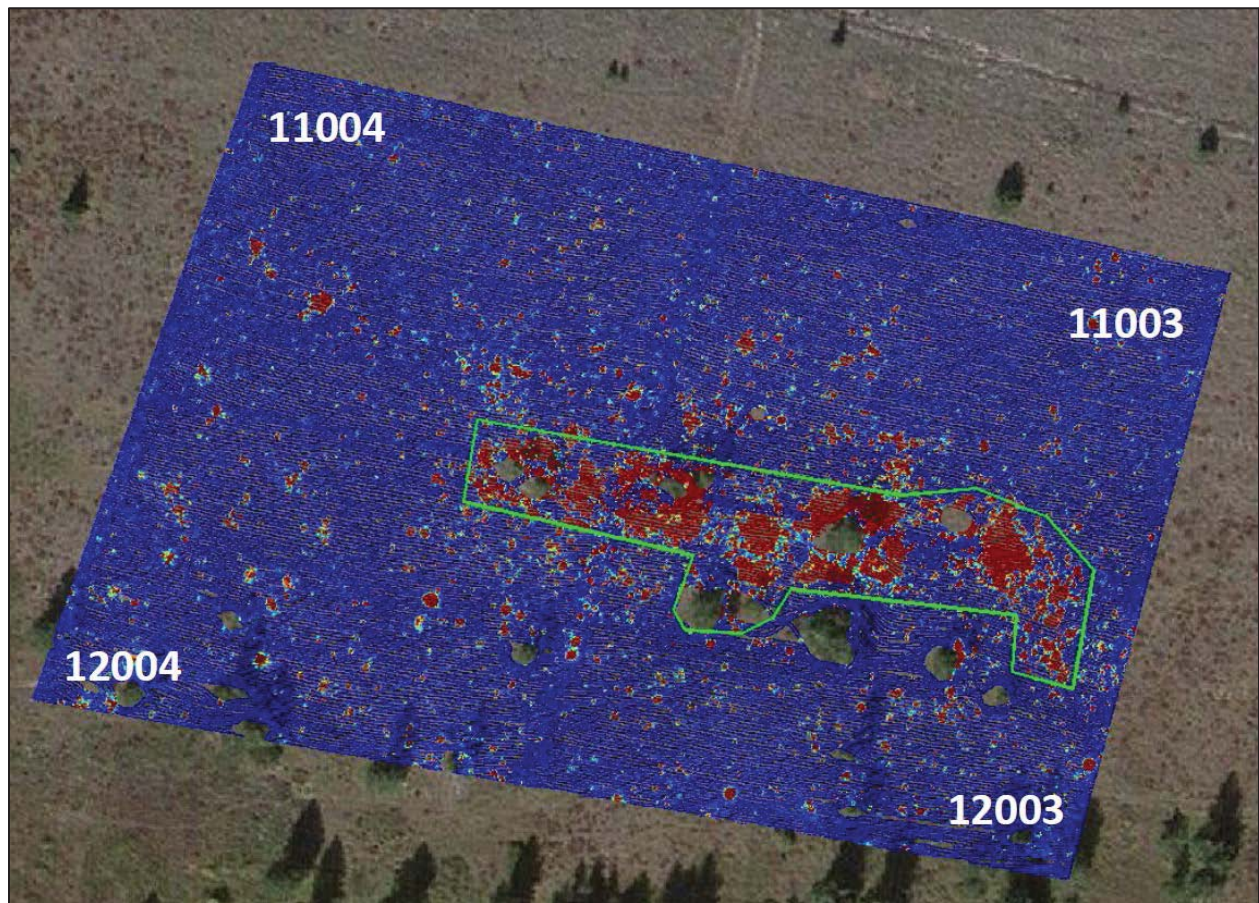
Figure 9. Area of Concentrated Anomalies
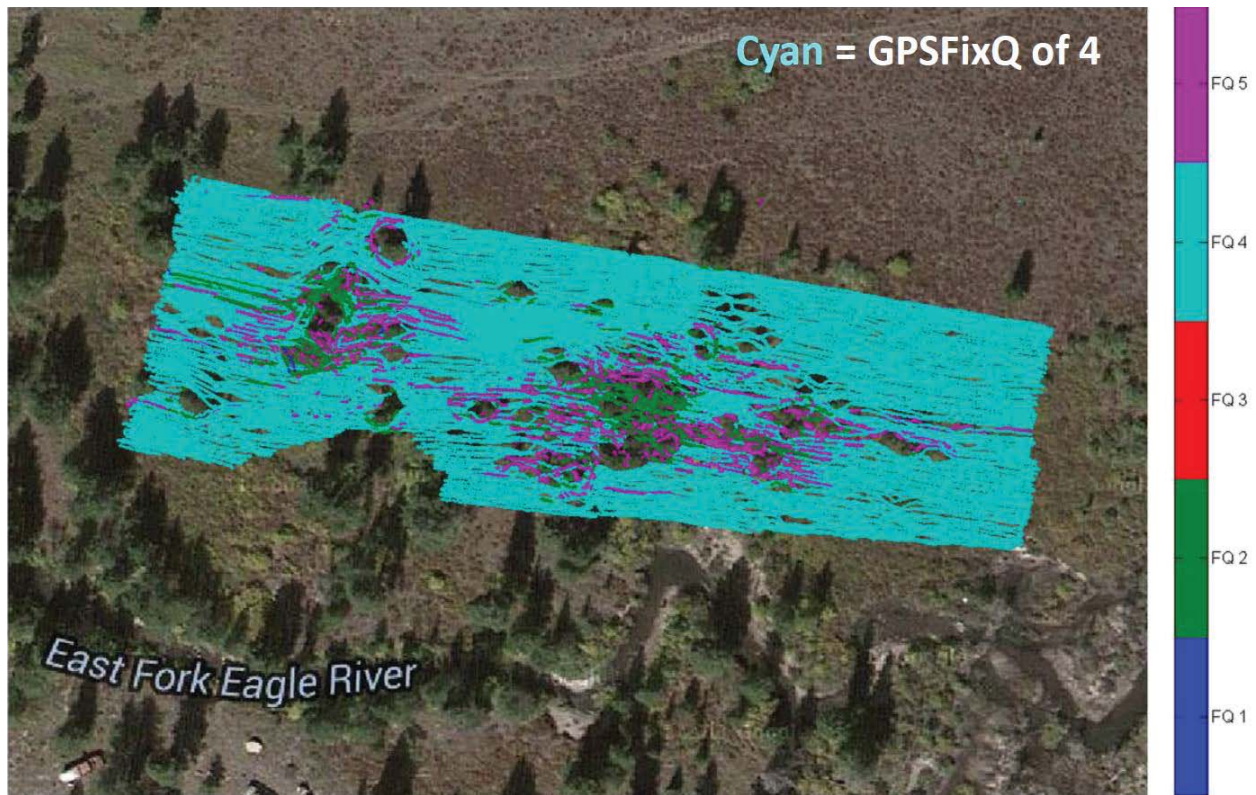
Figure 10. Areas with Difficult Data Collection

6.2 TEMTADS CUED DATA

6.2.1 Cued Processing

URS imported and processed cued data files for target and background locations by day. URS mapped the target and background locations in Montaj to verify spatial distribution. Using UX-Analyze QC tools, URS reviewed survey data outlier flags (i.e., current, flatline, GPS, IMU, and saturation), statistics and decay plot overlays for each background location, and leveled the survey data (i.e., removed background) based on proximal time and location.

6.2.2 Cued Classification

Black Tusk performed classification of cued data with their proprietary software using library matching and clustering.

6.2.3 Selection of Ground Truth Digs

Black Tusk selected 100 targets for ground truth digs to down select targets and refine project-specific anomaly classification. The 100 ground truth digs included three TOIs: two 81 mm mortars and one 40 mm illumination round.

6.3 DATA PRODUCTS

Black Tusk provided a final ranked anomaly list for both dynamic and cued classification using library matching and ground truth results. All seed items within the study area were recovered.

7.0   PERFORMANCE ASSESSMENT

The performance objectives for this demonstration are summarized in Table 1 and are repeated here as Table 3. The results for each criterion are discussed in the following sections.

Table 3. Quantitative Performance Objectives and Results

Performance Objective	Metric	Data Required	Success Criteria	Results
Data Collection Objectives				
Site-Specific Background	Establish background response	Background location response measurements	Comparison of background measurements at the same location during the course of the survey	DQO achieved as noted in Section 7.1.
Along-line measurement spacing	Point-to-point spacing from dataset	Mapped survey data	100% <40cm along line spacing, 98% <25 cm along-line spacing, and 80% <15 cm along line spacing	DQO achieved. Refer to Section 7.2.
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	100% of accessible area at 1.0-m line spacing, ≥85% coverage at 0.6-m line spacing and ≥98% coverage at 0.75-m line spacing calculated using UX-Process Footprint Coverage QC Tool	DQO achieved except as noted in Section 7.3.
Repeatability of IVS measurements	Amplitude of IVS seed items	Twice-daily IVS survey data	*Advanced Sensors Dynamic Survey:* RMS amplitudes ±30% at the 14th time gate. Down-track inverted location ±30 cm	DQO achieved as noted in Section 7.4.
	Measured target locations		*Advanced Sensors Cued:* Polarizabilities ±10%	DQO achieved as noted in Section 7.4.
Cued interrogation of anomalies	Instrument position	Cued mode data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	DQO achieved except as noted in Section 7.5.
Detection of all TOI	Percentage of detected seed items	Location of seed items and anomaly list	100% of seed items detected with 60 cm halo	DQO achieved. Refer to Section 7.6.
Analysis and Classification Objectives				
Maximize correct classification of TOI	Percentage of TOI placed in Category 1	Prioritized anomaly lists and dig results	Zero TOI among excavated anomalies classified as non-TOI.	Refer to Section 7.7 and Black Tusk ESTCP report.
Maximize correct classification of non-TOI	Percentage of correctly classified non-TOI	Prioritized anomaly lists and dig results	>75% non-TOI excavated were classified in Category 3 while retaining all TOI	Refer to Section 7.8 and Black Tusk ESTCP report.

| Performance Objective	Metric	Data Required	Success Criteria	Results
Specification of no-dig threshold	100% of TOI placed in Categories 1 or 2 and remainder of non-TOI placed in Category 3	Prioritized anomaly lists and dig results	Threshold specified to achieve criteria as stated above	Refer to Section 7.9 and Black Tusk ESTCP report.
Minimize number of anomalies that cannot be analyzed	Percentage of anomalies classified as Category 0	Inverted TEMTADS cued mode data and prioritized anomaly dig list	Reliable target parameters can be estimated for >95% of anomalies on the detection list	Refer to Section 7.10 and Black Tusk ESTCP report.
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Estimated and actual parameters (polarizabilities, XY locations, and depths [Z]) for seed items	Polarizabilities ±20% X, Y <15 cm (or 1 σ) Z <10 cm (or 1 σ)	Refer to Section 7.11 and Black Tusk ESTCP report.
Validation Digging				
Excavation of identified TOI	Percentage of anomalies classified as TOI verified to be "TOI" or "TOI-like" items	Prioritized anomaly list and dig results	>75% of intrusively investigated TOI anomalies are "TOI" or "TOI-like" anomalies	Refer to Section 7.12 and Black Tusk ESTCP report.
Excavation of identified non-TOI	Percentage of anomalies classified as non-TOI verified to be "non-TOI"	Prioritized anomaly list and dig results	100% of intrusively investigated non-TOI anomalies are non-TOI	Refer to Section 7.12 and Black Tusk ESTCP report.

7.1   OBJECTIVE: SITE SPECIFIC BACKGROUND

URS evaluated the dynamic survey data and selected potential background locations throughout the study area. The field team collected a series of measurements at the center of the identified location plus 0.4 m offsets in each of the four cardinal directions. After review by the data processor, the flagged location was marked as a suitable background location for cued survey. The background measurements were compared to others taken at the same location during the course of the cued survey.

## 7.2   OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The sample separation objectives of at least 80% at 15-cm spacing, 98% at 25-cm spacing, and 100% at 40-cm spacing were met.

For grids 11001-11005 and 12001-12005, 83.3% of the data met the along-line objective of less than 15-cm spacing, 99.8% met the 25-cm spacing objective, and 100% met the 40-cm spacing objective. These results exclude areas that could not be surveyed due to vegetation. Figures 11, 12, and 13 show blue flags for the separations larger than 15 cm, 25 cm, and 40 cm, respectively.

For grids 13001 and 13002, 90.8% of the data met the along-line objective of less than 15-cm spacing, 99.7% of the data met the 25-cm spacing objective, and 100% of the data met the 40-cm spacing objective. These results exclude areas that could not be surveyed due to vegetation and terrain. Figures 14, 15, and 16 show blue flags for the separations larger than 15 cm, 25 cm, and 40 cm, respectively.
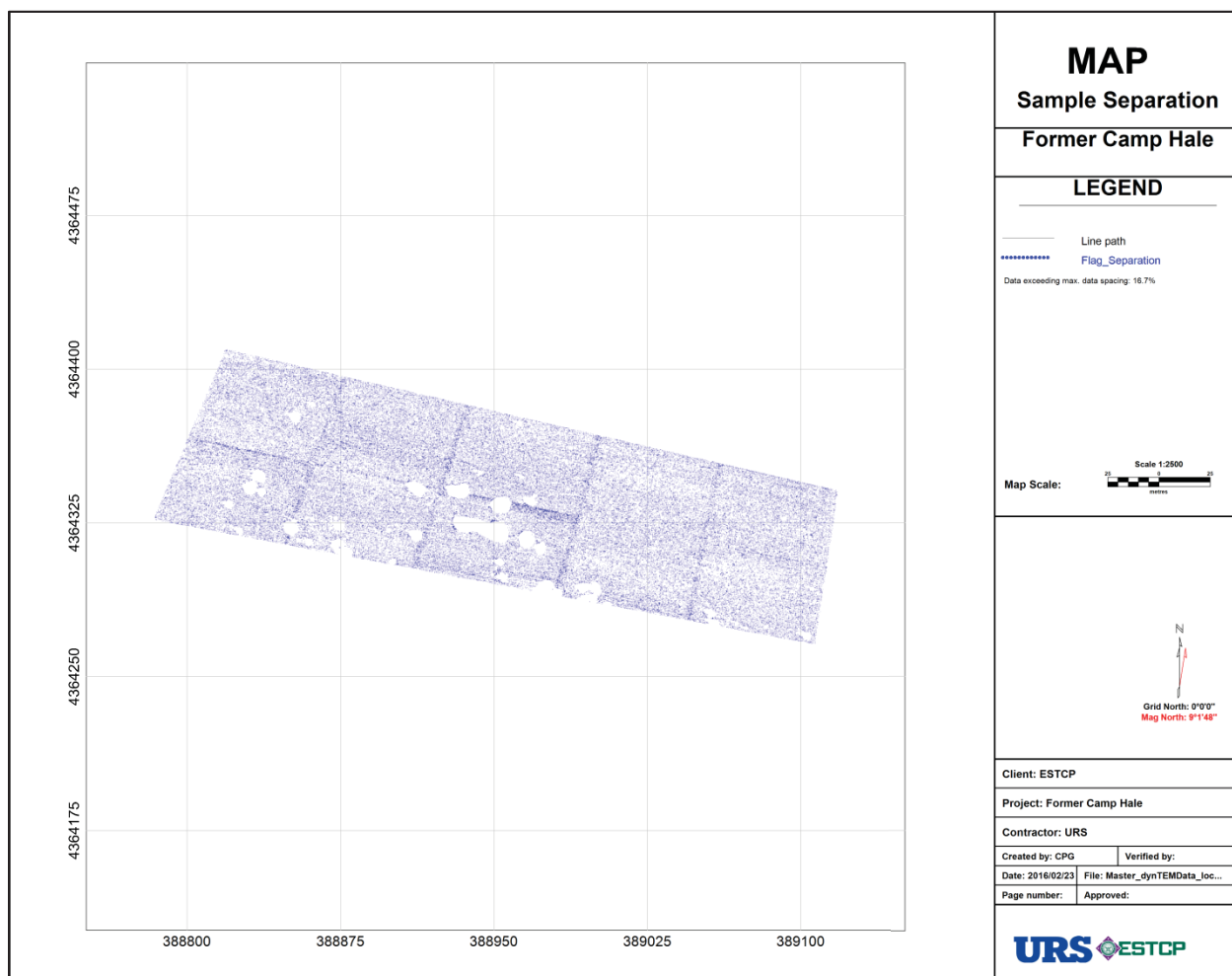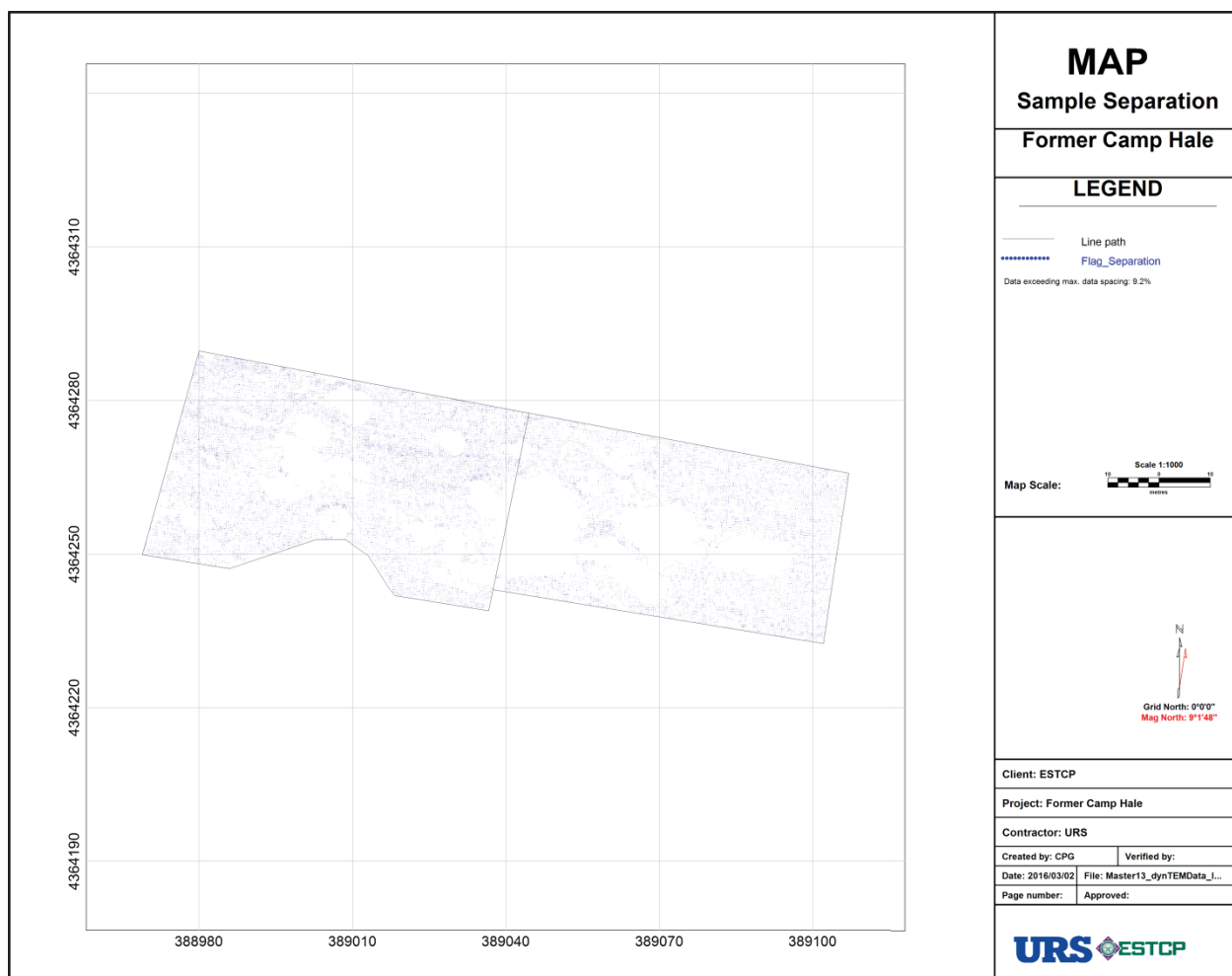

Figure 11. Sample Separation 15 cm, Grids 11001-11005 and 12001-12005
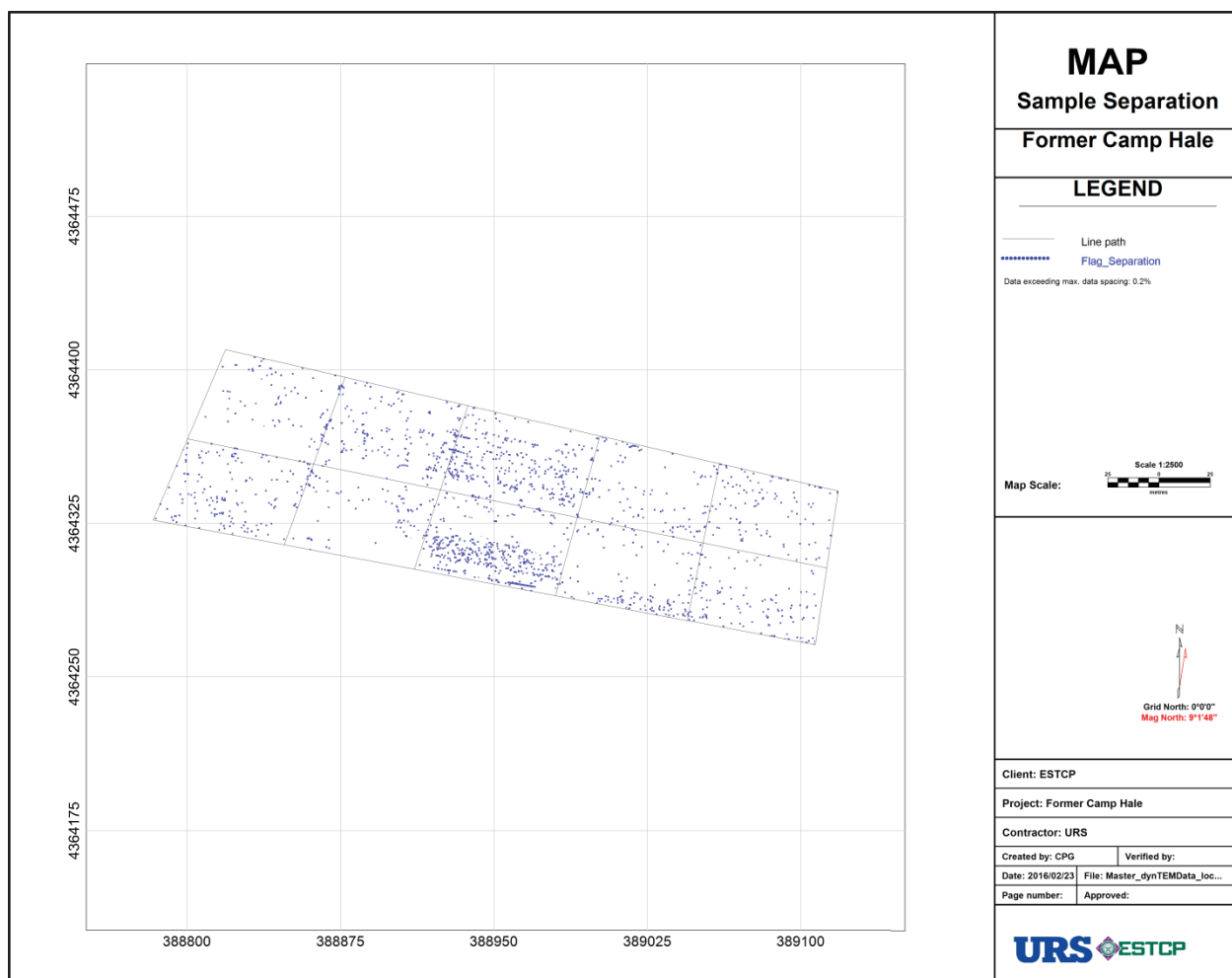
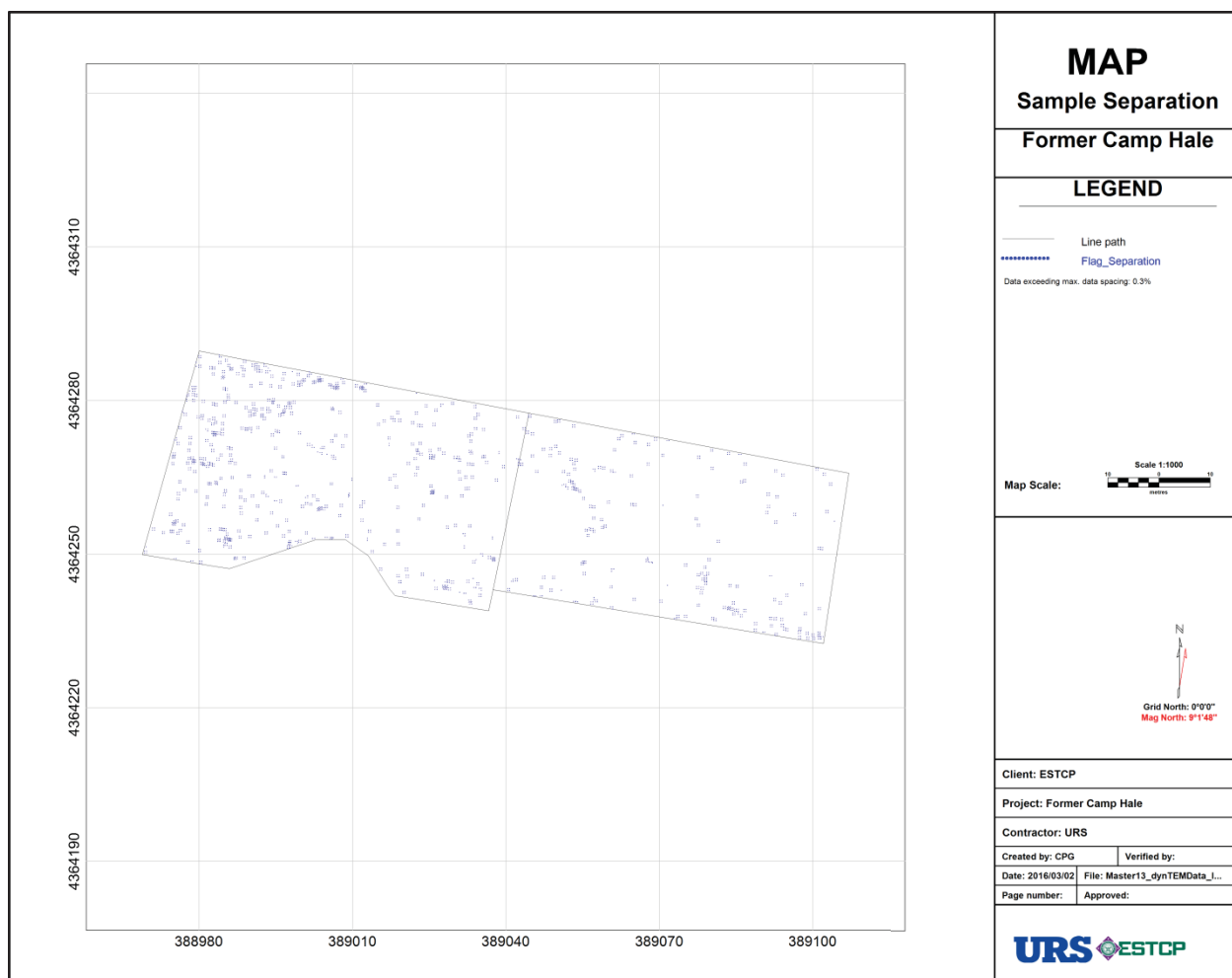**Figure 12. Sample Separation 25 cm, Grids 11001-11005 and 12001-12005**
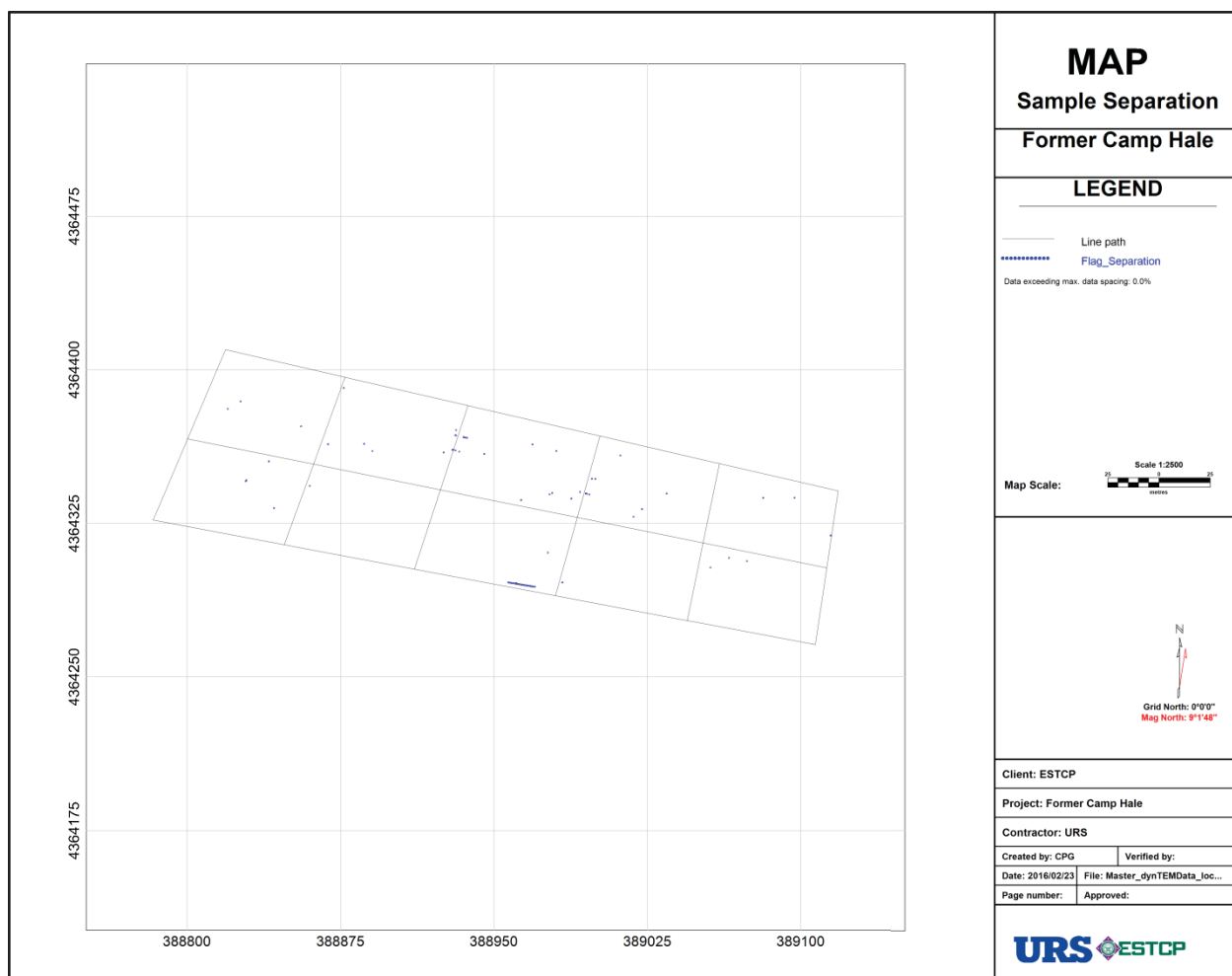
Figure 13. Sample Separation 40 cm, Grids 11001-11005 and 12001-12005
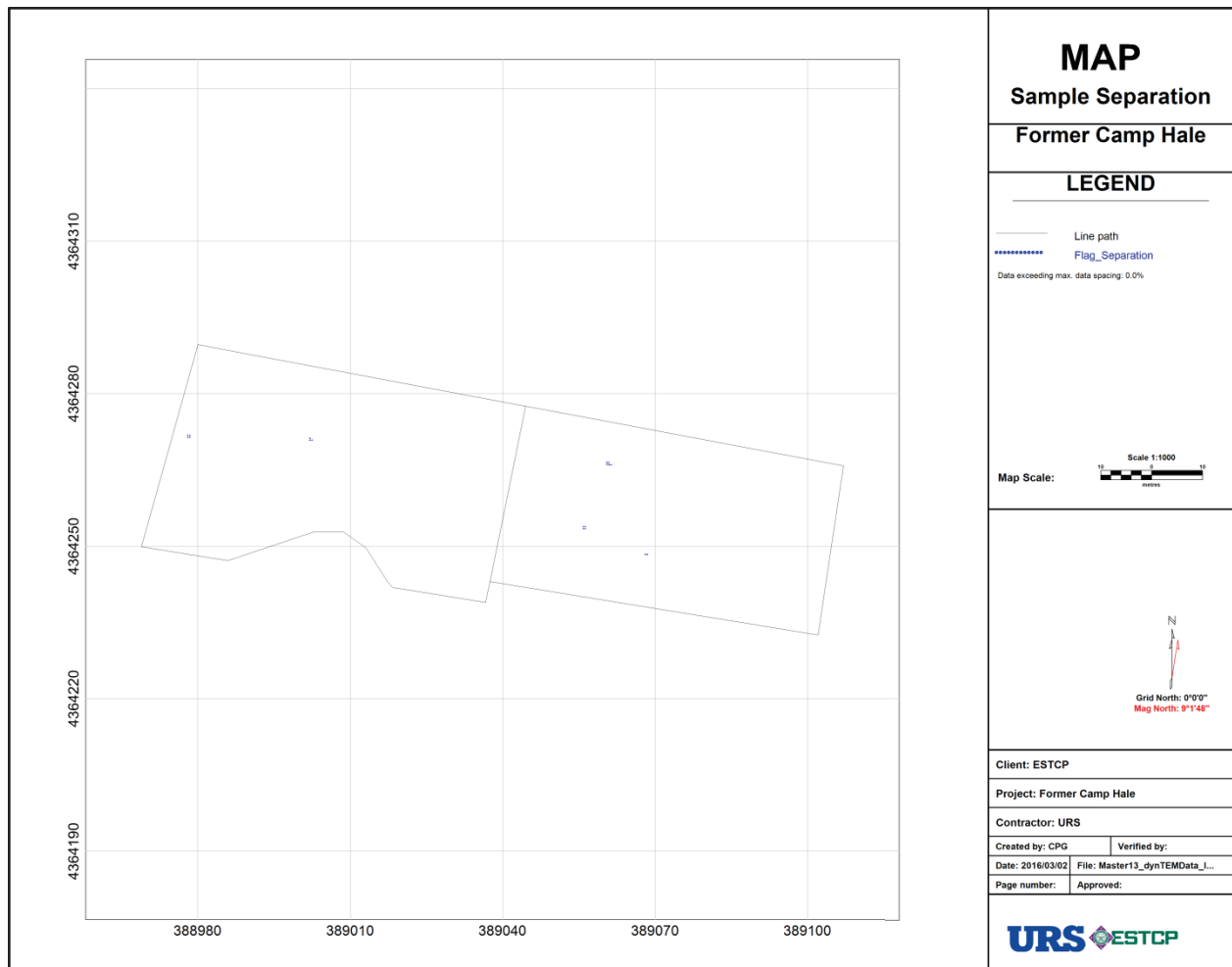
Figure 14. Sample Separation 15 cm, Grids 13001 and 13002

Figure 15. Sample Separation 25 cm, Grids 13001 and 13002

**Figure 16. Sample Separation 40 cm, Grids 13001 and 13002**

7.3 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The footprint coverage objectives of at least 85% coverage at a 0.6-m instrument footprint, at least 98% coverage at 0.75-m, and 100% coverage at 1-m were met except as noted for the 1-m instrument footprint in the 13001-13002 grids.
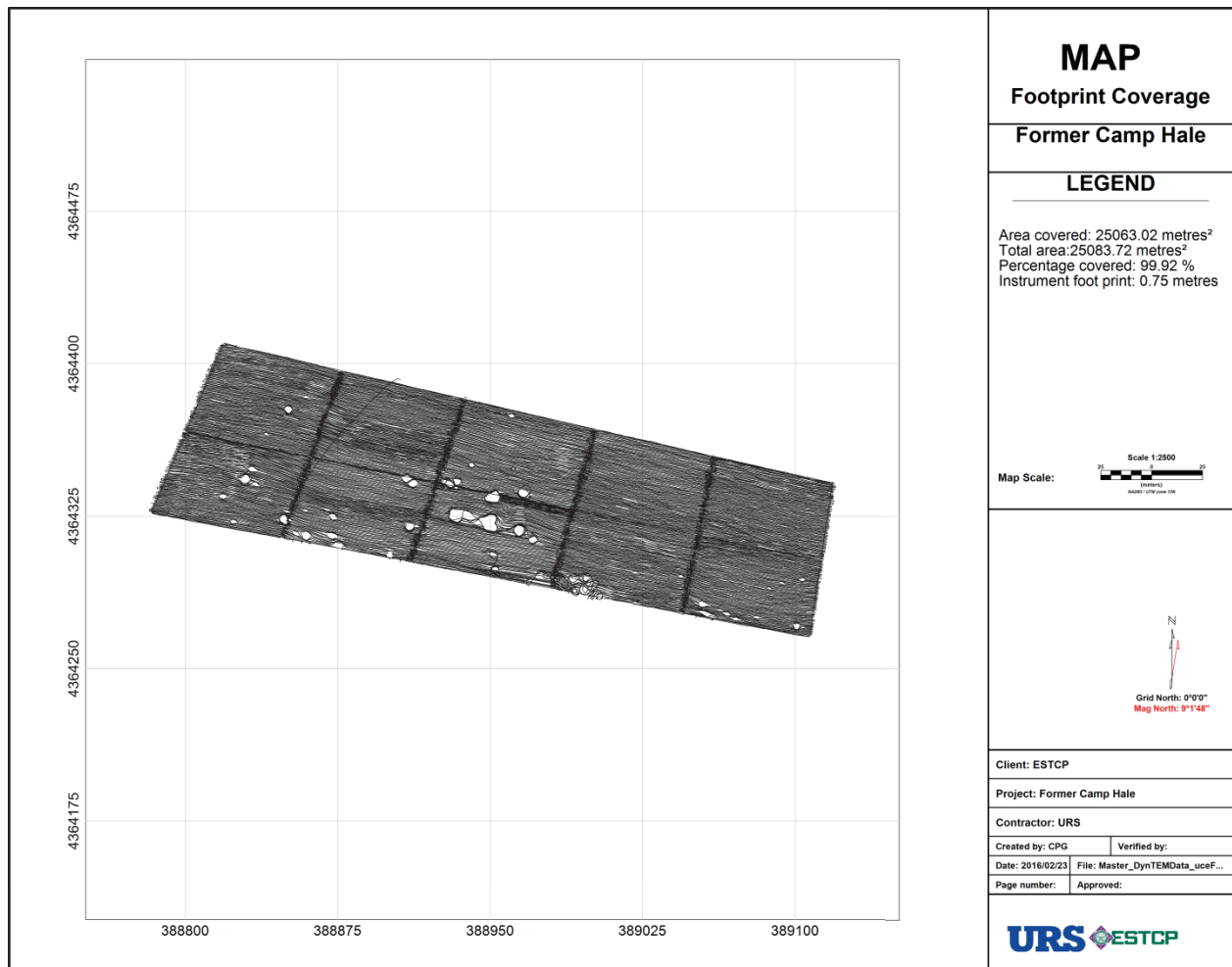
For grids 11001-11005 and 12001-12005, GPS coverage and terrain were good, and the objectives were met. When using 0.6-m instrument footprint, 99.4% of the survey area was covered. When using 0.75-m spacing, 99.9% of the survey area was covered. When using 0.1-m spacing, 100% of the survey area was covered. These results exclude areas that could not be surveyed due to vegetation. Figures 17, 18, and 19 show coverage in grids 11001-11005 and 12001-12005 using 0.6-m, 0.75-m, and 1-m instrument footprints, respectively.

For grids 13001 and 13002, steep terrain and tree cover limited accessibility and GPS coverage. The objectives were met for 0.6-m and 0.75-m instrument footprint. When using 0.6-m instrument footprint, 96.3% of the survey area was covered. When using 0.75-m spacing, 98.3% of the survey area was covered. The 1-m instrument footprint achieved 99.7% coverage instead

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of the required 100% coverage. These results exclude areas that could not be surveyed due to vegetation and steep terrain. Figures 20, 21, and 22 show coverage in grids 13001 and 13002 using 0.6-m, 0.75-m, and 1-m instrument footprints, respectively.
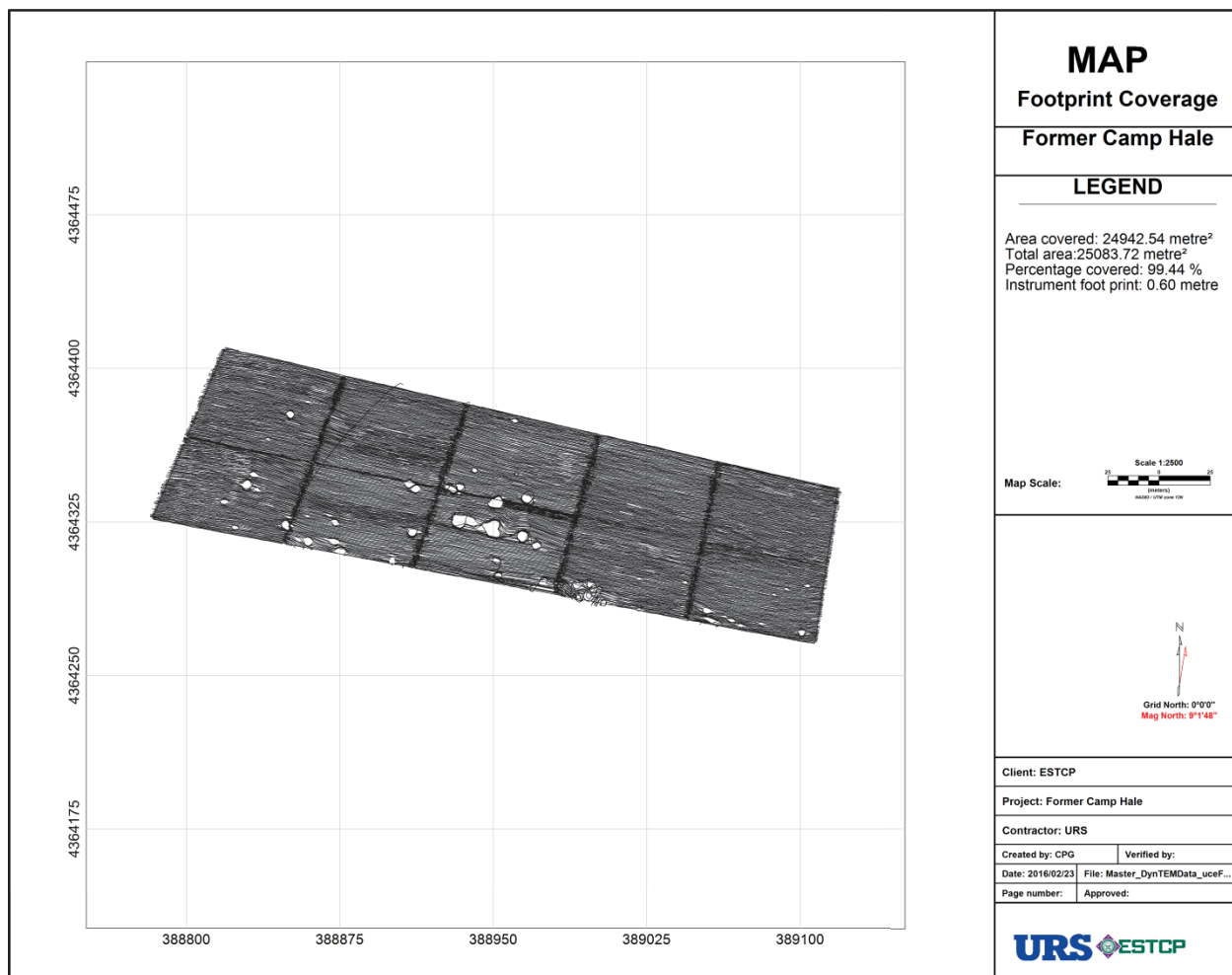
Figure 17. Footprint Coverage at 0.6 m, Grids 11001-11005 and 12001-12005

Figure 18. Footprint Coverage at 0.75 m, Grids 11001-11005 and 12001-12005
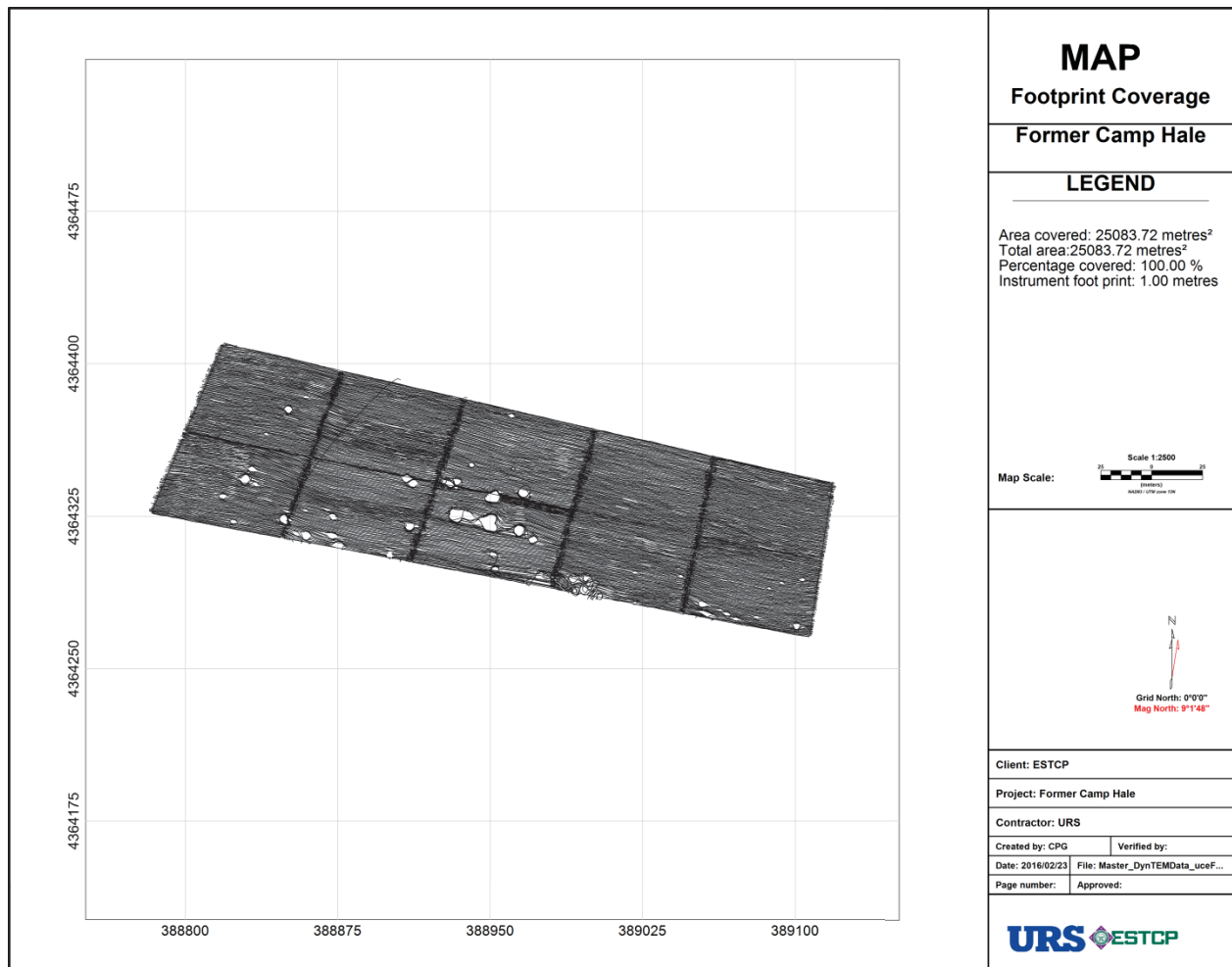
Figure 19. Footprint Coverage at 1 m, Grids 11001-11005 and 12001-12005

Figure 20. Footprint Coverage at 0.6 m, Grids 13001 and 13002

Figure 21. Footprint Coverage at 0.75 m, Grids 13001 and 13002

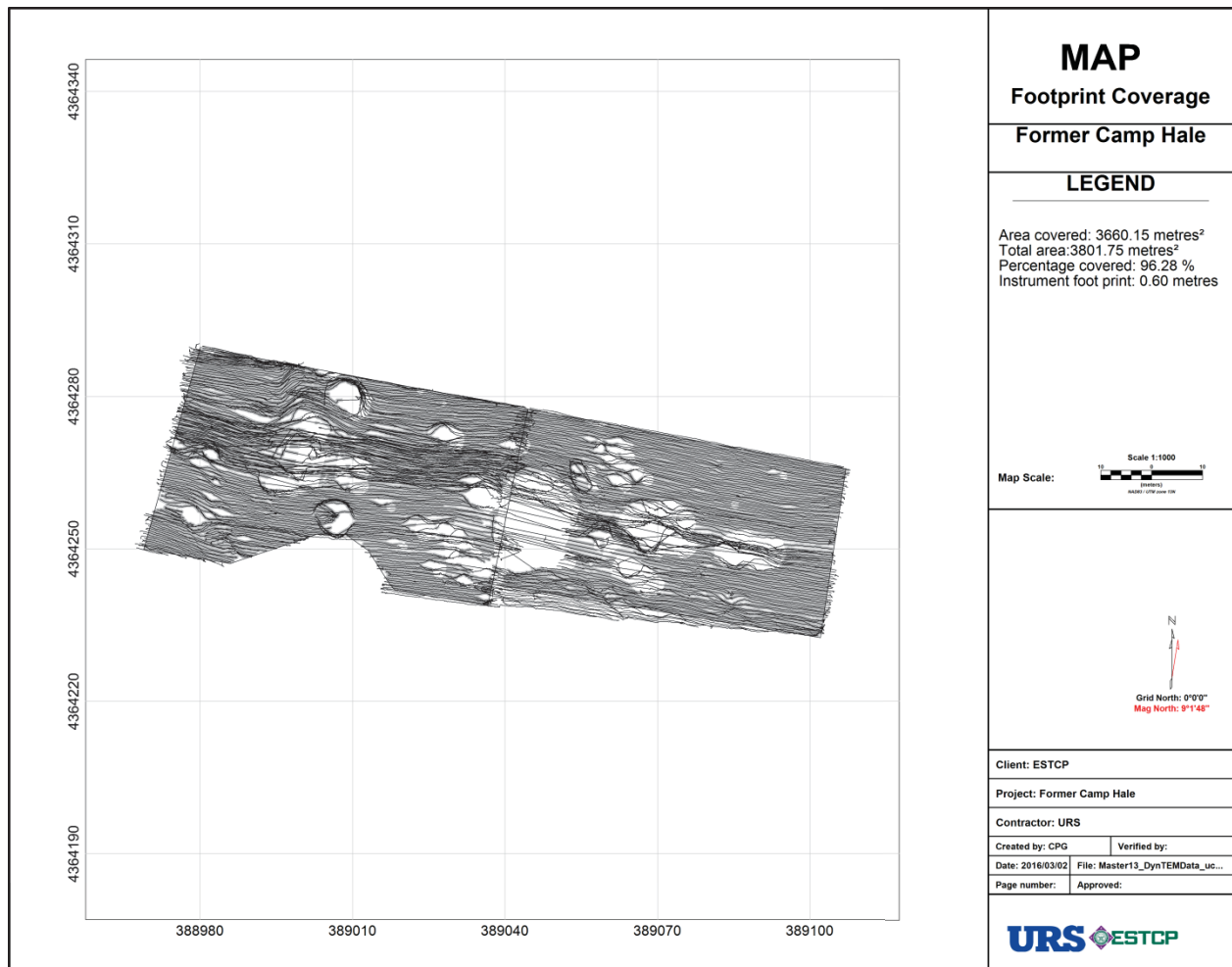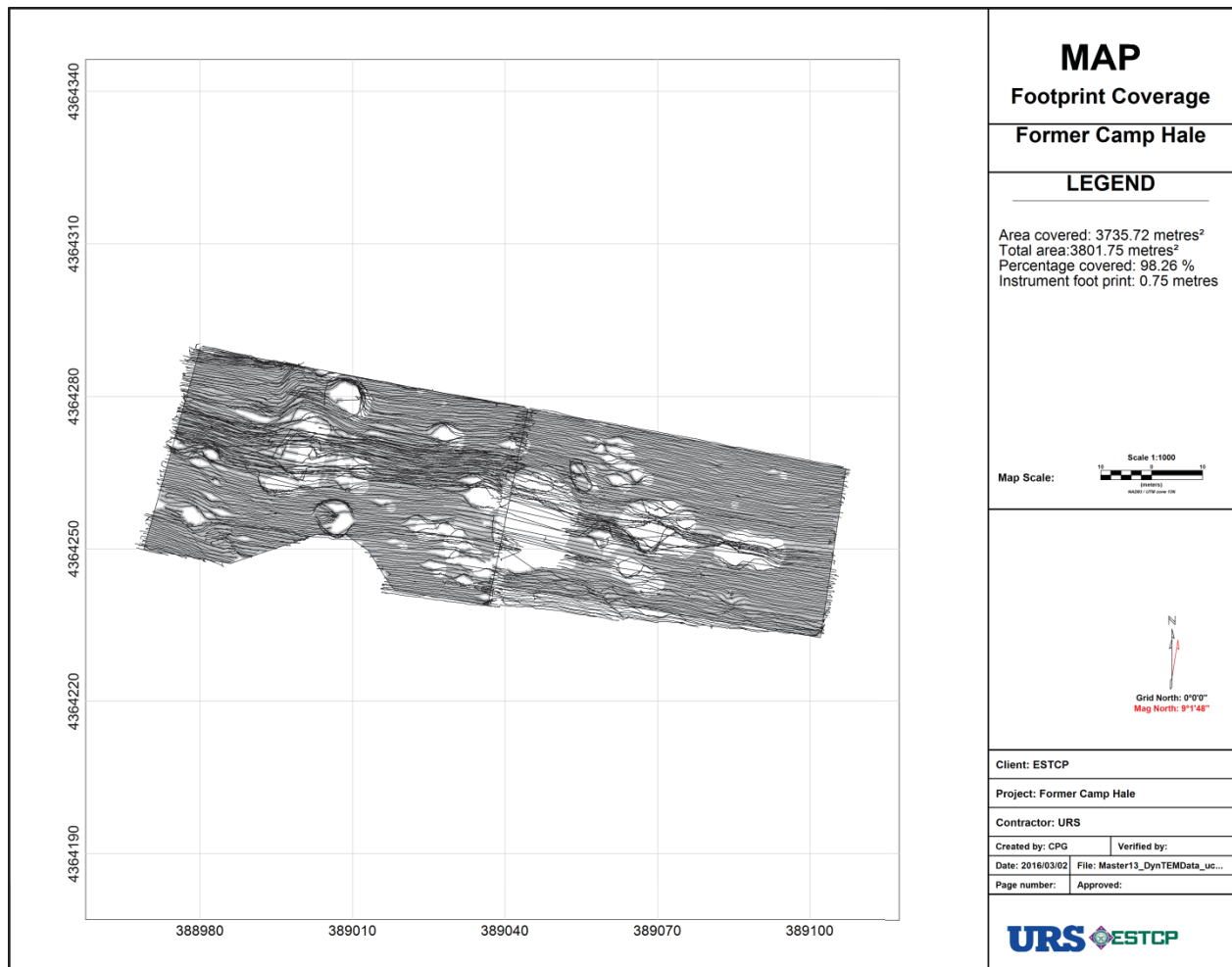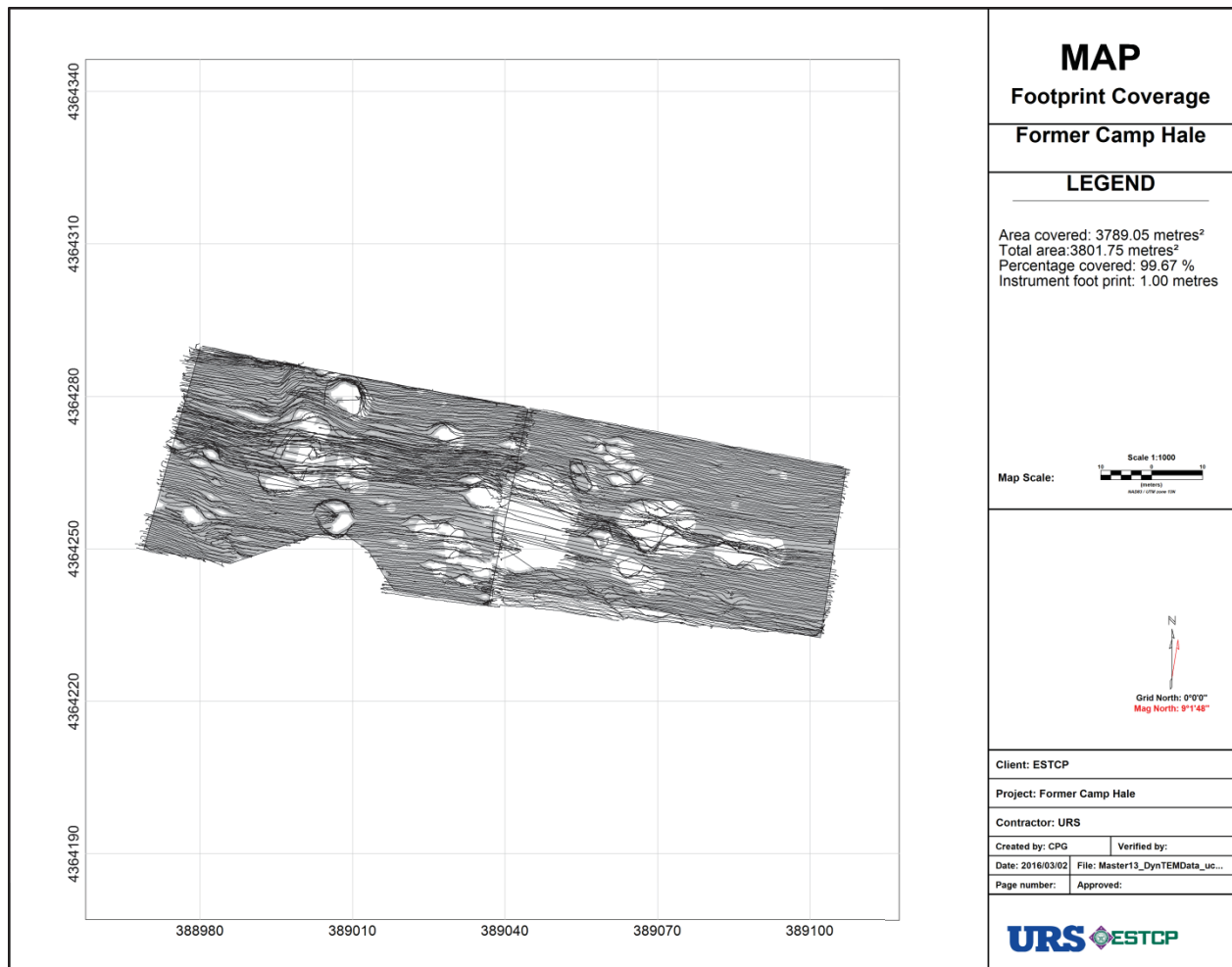**Figure 22. Footprint Coverage at 1 m, Grids 13001 and 13002**

7.4   OBJECTIVE: IVS RESULTS

For the dynamic survey, since inversion of dynamic data was not possible in UX-Analyze, URS performed daily review of peaks within UX-Analyze. Black Tusk provided data to support this objective during the beginning of the survey. The RMS amplitudes were within ±30% at the 14th time gate for the days data were available (fully complete grids 11002-11004, 12001-12004, and 13001; partially complete grids 11001, 12004, and 13002). The down-track inverted location was within 30 cm for grids 11001-11005, 12001-12005, and 13001-13002.

For the cued survey, since the exact polarizabilities of each seed item are not known (each seed was not measured for comparison), they were estimated by comparing against the highest library match for each item. All cued seed items matched to a medium ISO at 0.97 or higher. The deltas for the inverted locations in the X and Y directions were within 5 cm and the Z direction was within 2 cm.

7.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

For the entire project area, 99.3% of the instrument positions were within 40 cm of the cued flag location. For cued data collected in grids 11001-11005 and 12001-12005, where GPS coverage and terrain were good, all but one of the 1,375 instrument positions (99.9%) were within 40 cm of the cued flag location. For cued data collected in grids 13001 and 13002, where GPS coverage was spotty and terrain challenging, all but 12 of the 366 instrument positions (96.7%) were within 40 cm of the cued flag location.

7.6 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

All of the blind seeds (medium ISO) were detected within 60 cm of their predicted locations.

7.7 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

The prioritized anomaly lists placed 100% of recovered TOI in the dig/ground truth portion of the list. Refer to the Black Tusk ESTCP report for more information.

7.8 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

No TOI were recovered in the QC digs past the stop dig point. Refer to the Black Tusk ESTCP report for more information.

7.9 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

TOI were recovered in the dig portion of the list, and no TOI were recovered in QC digs past the stop dig point. Refer to the Black Tusk ESTCP report for more information.

7.10 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Reliable target parameters were estimated for 99.9% of the dig list. Several areas were delineated by the project team as unsuitable for advanced classification and were excavated (i.e., mag and dig). Refer to the Black Tusk ESTCP report for more information.

7.11 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

Seed items were correctly identified. Refer to the Black Tusk ESTCP report for more information.

7.12 OBJECTIVE: EXCAVATION OF ANOMALIES

The objective will be considered to be met if greater than 75% of the items identified as TOI are TOI or TOI-like anomalies and 100 % of the items identified as non-TOI are non-TOI. Refer to the Black Tusk ESTCP report for more information.

8.0   COST ASSESSMENT

The cost elements traced for this demonstration are detailed in Table 4.

Table 4. Project Costs

Cost Element	Data Tracked During Demonstration	Estimated Costs
Project Planning	Develop project-specific documents: • Project Kickoff • Demonstration Plan • SSHP	$34,987
Site Preparation	Set up onsite project area Vegetation trimming Install blind seed items • Labor • Equipment rental • Supplies • Travel	$81,304
TEMTADS Data Collection and Processing	3-4 people (field team) data collection and processing • Dynamic data collection on 10.5 acres • Cued data collection on 7.6 acres: – 1,742 anomalies (2,468 cued shots including re-collect, background, IVS, and sensor function measurements) Project Geophysicist • Equipment rental • Supplies • Travel	$234,575
Validation Digging	8 UXO Technicians (includes four days awaiting regulatory approval of final dig list) Equipment rental Supplies Travel • 1,371 targets (includes mag/dig locations that had high concentration of anomalies or accessibility issues) • 2,650 anomalies (including anomalies found in 30+ cm radius of target)	$236,169 $89 per anomaly $172 per target location

8.1   COST DRIVERS

The primary cost considerations associated with the selection and broad implementation of advanced geophysics and classification technologies are:

- Cost of data collection with advanced sensor arrays (primarily labor, per diem, and equipment rental/repair);
- Cost of data processing, analysis, and anomaly classification (primarily labor); and
- Cost savings associated with reduction in number of anomalies requiring intrusive investigation (primarily labor, per diem, and equipment rental).

8.2   COST BENEFIT

The primary driver for developing advanced geophysics and classification technologies is to reduce the total cost of executing munitions responses. DoD recognizes that a large portion of the

munitions response budget is spent excavating and removing harmless metal fragments and non-munitions-related metal from MRSs. The implementation of advanced geophysics and classification has been demonstrated to reduce the total number of anomalies requiring intrusive investigation (i.e., excavation) by 60% to 90% in demonstration/validation projects. For advanced geophysics and classification to be broadly employed, these technologies must cost less to implement than the intrusive investigations that would be avoided by their implementation.

The majority of the target locations and recovered items at former Camp Hale were in areas that were not conducive to advanced classification where "mag and dig" were performed. These included an area with a high concentration of anomalies and areas with instrument accessibility issues. These mag and dig areas accounted for 999 (73% of total) target locations and 2,018 (76% of total) recovered metallic items.

9.0   IMPLEMENTATION ISSUES

Advanced geophysical sensor and advanced data analysis methods in a production environment were used to characterize MEC hazards at Former Camp Hale. Because URS' role in the Live Site Demonstration Program is to evaluate the implementation of these advanced sensors and classification methods from the perspective of a large-scale MMRP production company, URS documented issues/recommendations that will support implementation on an industry-wide scale.

9.1   TEMTADS DATA COLLECTION

9.1.1   Longer Tx/Rx Cables

As described in Section 2.1.1, an alternate instrument configuration was tested where the standard Tx and Rx cables were replaced with longer versions. The standard configuration and weight of the TEMTADS 2x2 cart (approximately 125 pounds) and backpack (approximately 35 pounds) made it difficult to maneuver for smaller statured field personnel. The use of longer cables allowed the backpack to be carried by personnel separate from the cart operator during data collection. Additionally, it allowed the backpack to be staged on the ground while personnel lifted the cart into the bed of the pickup truck for daily transport between the demonstration area and storage area. However, use of the longer cables resulted in faster battery charge depletion than with the standard-length cables. This required more diligent monitoring of battery usage by field personnel.

9.1.2   Data Collection Software

The field team experienced issues with the data collection program throughout the project. Program freezes required restarting the computer and additional QC checks. The instrument developers were aware of issues with serial communication inherent in the system. An updated data collection program was released at the end of the project, but the field team did not test it due to time constraints.

9.1.3   GPS Base Station Setup

Field data were collected using an RTK GPS base station set up over the ESTCP 1 monument location. However, due to miscommunication between transitioning field personnel, coordinates other than the surveyor's coordinates were used for the monument/base station location in the GPS unit. Upon recognition of the inaccuracy, the project team decided to continue using the alternate coordinates, so that the project data would be precise. A "readme" file with specific coordinate shift instructions to align the project data to surveyor's data is included with the project data.

10.0 REFERENCES

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Appendix A: POINTS OF CONTACT

Point of Contact	Organization	Phone E-mail	Role
Dr. Anne Andrews	ESTCP Program Office 4800 Mark Center Drive, Suite 17D08 Alexandria, VA 22350-3605	571-372-5379 anne.andrews@osd.mil	Acting Director, ESTCP
Dr. Herb Nelson	ESTCP Program Office 4800 Mark Center Drive, Suite 17D08 Alexandria, VA 22350-3605	571-372-6400 herbert.nelson@osd.mil	Program Manager, Munitions Response
Ms. Victoria Kantsios	URS Group, Inc. 2450 Crystal Drive Suite 500 Arlington, VA 22202	703-418-3030 victoria.kantsios@aecom.com	Principal Investigator
Mr. Brian Helmlinger	URS Group, Inc. 2450 Crystal Drive Suite 500 Arlington, VA 22202	703-418-3340 brian.helmlinger@aecom.com	Principal-In-Charge
Ms. Cheryl Gannon	URS Group, Inc. 2450 Crystal Drive Suite 500 Arlington, VA 22202	703-418-3246 cheryl.gannon@aecom.com	Geophysicist
Dr. Len Pasion	Black Tusk Geophysics 1755 West Broadway Vancouver, BC V6J 4S5 Canada	604-428-3380 len.pasion@btgeophysics.com	Geophysicist
Dr. Dean Keiswetter	Acorn Science & Innovation, Inc. 1000 Centre Green Way Suite 200/232 Cary, NC 27513	703-995-9872 x702 dkeiswetter@acornsi.com	Geophysicist